Endodontology

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Thieme

VISIT…

Endodontology

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It is with great pleasure and gratitude that I dedicate
this book to my wife Uta Annette Baumann-Giedziella
and to our three children
Helena Uta Regina
Raffael Michael Alexander
Tobias Jonas Aurel

Michael A. Baumann

Preface

Over a decade has passed since the *Color Atlas of Endodontology* was published: a relatively short period of time, yet full of new and revolutionary developments.

In the foreword to the original atlas, the microscope of course was mentioned, but mainly in connection with microsurgical techniques and apicectomy. Since then, microscopes have become an indispensable part of endodontic treatment and many dentists and endodontologists have microscopes at their disposal.

Nickel-titanium instruments were already a feature 10 years ago, however, in the ensuing time many innovative designs have been added. Torque-controlled motors or specially designed handpieces have become part of everyday endodontic practice and the connection to electronic working length measurement has been achieved in many cases.

Bacteriology and immunology have made substantial progress and the assessment of pulpal infection has become more detailed. We can expect the future to bring developments in the form of newer and more effective irrigation solutions, medicated dressings, and root canal filling materials. MTA (**m**ineral **t**rioxide **a**ggregate), MTAD (**m**ixture of **t**etracycline, an **a**cid and a **d**etergent), and Bioglass are the first indications of such developments.

Heating techniques for root canal obturation continue to improve and have become easier and more reliable to use with further developments in equipment. At the same time, cold filling systems for gutta-percha have been successfully introduced to help overcome the problem of shrinkage due to the polymerization that occurs during heating.

The ongoing progress in adhesive fixation technology has allowed redefinition and further development of the concepts of root canal filling, postendodontic provision of tooth or dentinlike materials, as well as the avoidance of apical and coronal leakage.

Taking into consideration existing biologic structures and principles, this book reviews the areas of traumatology, endodontics of the deciduous tooth, and procedures in deciduous and mixed dentition, with implementation of new ideas.

Surgical procedures are being increasingly replaced by evermore successful primary endodontic treatment and by a growing rate of retreatment. Indeed, endodontic retreatment is experiencing a revival. For a long time endodontic retreatment was an unpopular procedure—time-consuming, often frustrating, and with not much promise of success. However, the introduction of microscopes, ultrasound and NiTi files, and heating equipment has led to endodontic retreatment becoming faster, easier and very successful. Implantology, the great rival of endodontic procedures, has stimulated the discourse on the significance, purpose, and limitations of endodontic treatment.

This book has been prepared with careful consideration of the constructive criticism of the original atlas, and we have included the suggestions for improvement: The section on deciduous dentition has been expanded, and the issue of interaction between endodontics and the organism as a whole has been discussed. More space has been dedicated to the problems of resorption and perforation, as well as to failures and problem solutions, putting a new slant on the success rates of earlier years. And, to conclude, a note on the images—indispensable in a color atlas—that have a totally new degree of quality owing to the use of the now common microscope images of clinical treatment steps.

Endodontology is the work of many authors from all over the world. On the one hand it mirrors the age of globalization, and on the other hand it is the "next episode" of a continuing specialization of singular aspects of an individual area. Being but a small component of dentistry, and consequently of medicine, endodontology itself contains such vast amounts of details and facts that no single author would be capable of mastering and exploring in depth the individual aspects of the whole.

Thanks go therefore to all the contributors from East to West, and North to South, without whose highly qualified expertise this color atlas would not have been possible.

So, dear reader, we present to you *Endodontology* and we hope you enjoy reading the text and viewing the images.

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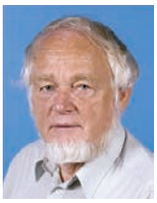

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Basic Principles

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1 Histology of the Pulp

From a functional point of view, pulp essentially exists to allow the constant formation of new dentin to compensate for natural occlusal abrasion. Therefore, the morphology of pulpal tissue changes throughout life and it should be viewed as a dynamic organ.

Histologically, pulp consists of specialized, loosely woven connective tissue, which is responsible for formation of new dentin at the periphery of the pulp chamber. Odontoblasts, which line the wall of the entire pulp chamber, lay down the so-called "reparative dentin" in response to external stimuli (e.g., bacterial invasion into dentin tubuli).

The cells in the pulpal connective tissue consist primarily of undifferentiated fibroblast-like cells (pulpoblasts). Following external stimulation, these cells can differentiate into odontoblasts or into fibroblasts that produce fibrodentin.

It is possible to differentiate between coronal pulp and root canal (radicular) pulp. Coronal pulp consists of a loose network of connective tissue in which blood vessels and nerve fibers are embedded. These vessels and nerve fibers reach the coronal pulp via the apical foramen and the root canal itself. Within the pulp chamber, these entities branch to form rich vascular and nerve plexuses in the subodontoblastic layer. In addition to the loose connective tissue, the central part of the root pulp contains collagen fibers subjacent to the odontoblastic layer, and the blood vessels and nerve fibers course through this fibrous matrix. At the apical foramen, the pulpal tissue blends with the periodontal tissues.

1.1 The pulp of a mandibular molar

The coronal pulp fills the wide pulp chamber. The various zones of dentin, predentin, the odontoblastic layer, and the cell-poor and cell-rich layers can be seen.

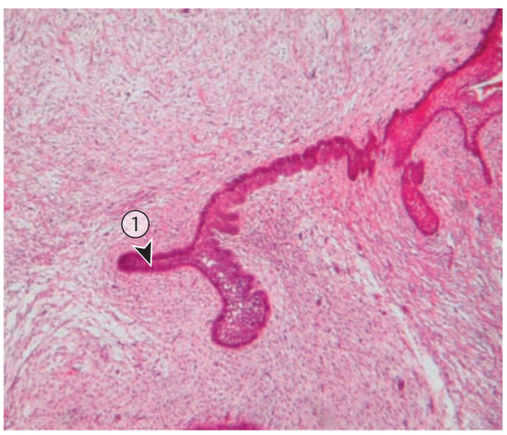
The pulpal tissue itself consists of loose connective tissue. Individual vascular elements are seen in both transverse and longitudinal sections (courtesy of Professor Dr. W. Ketterel, Mainz, Germany).

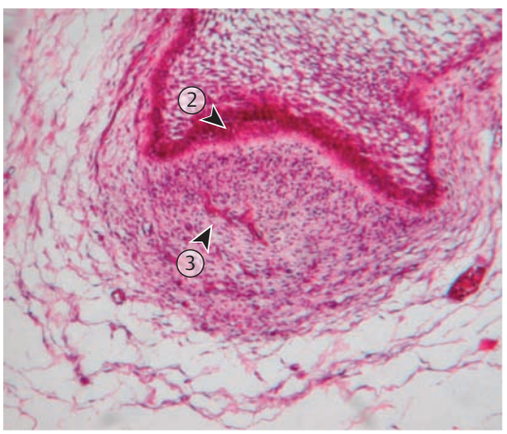
Embryonic Development of the Pulp

The pulp develops from the mesenchymal cells of the cranial ectomesenchyme, which develops from the cranial neural crest. Invagination of the superficial ectoderm of the oral cavity is followed by formation of the dental primordia, in which the individual tooth buds develop. A complex and multifaceted induction cascade between the ectoderm and mesenchyme leads to the concentration of mesenchymal cells immediately subjacent to the ectoderm of each tooth bud.

The enamel organ develops from the ectoderm surrounding condensed mesenchymal cells. Additional signaling molecules released from the invaginated epithelium into the mesectoderm stimulate the differentiation of mesenchymal preodontoblasts at the ectodermal–mesenchymal border; these cells then begin to secrete pre-dentin.

As the mineralization of dentin begins, cellular processes begin to form at the apical ends of the preodontoblastic cells. These so-called odontoblastic processes continue to produce predentin, therefore ensuring that the dentin layer becomes ever thicker. Vascular elements proliferate at the apical aspect of the tooth bud and extend into the forming dental pulp.

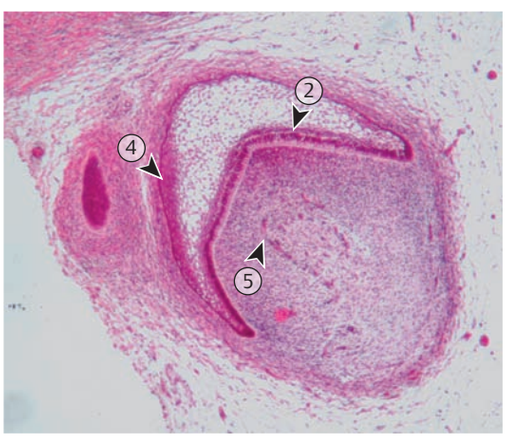


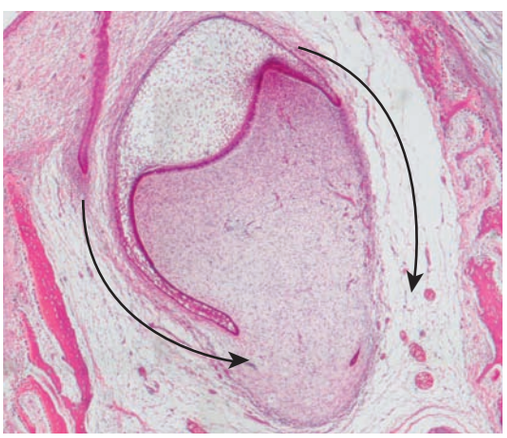


1.2 Development of the tooth bud

Left: The superficial oral ectoderm invaginates into the subjacent mesenchyme, forming the tooth bud (**1**).

Right: The inner enamel epithelium induces condensation of the mesenchymal cells (**2**), as a result of which the mesenchyme (**3**) thickens subjacent to the enamel epithelium.

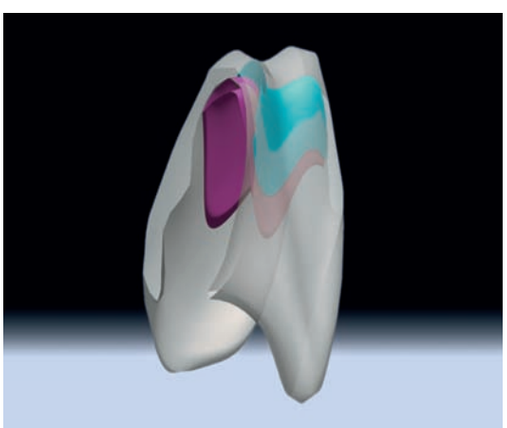


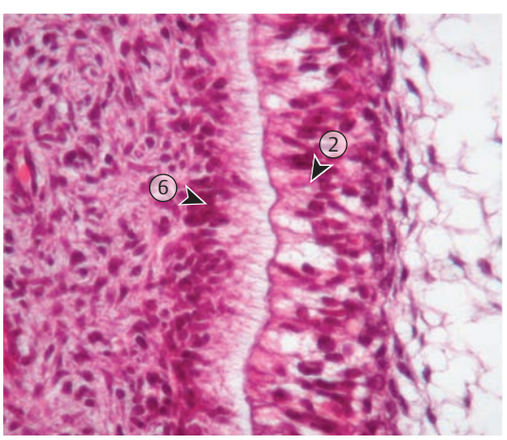


1.3 Development of the pulp

Left: The internal (**2**) and external (**4**) enamel epithelia surrounding the thickening pulpal mesenchyme (**5**).

Right: As a result of further growth of the tooth bud into the mesenchyme (arrows indicate the growth direction), one can differentiate between the coronal pulp and radicular pulp.





1.4 Differentiation of odontoblasts

Left: Three-dimensional reconstruction of the bud of tooth 81. The enamel (blue) covers the dentin (pink) like a cap. The enamel organ (light gray) surrounds the pulp chamber.

Right: The odontoblasts (**6**) begin to secrete predentin. The odontoblastic processes start to develop (**2** = inner enamel epithelium).

Coronal Pulp

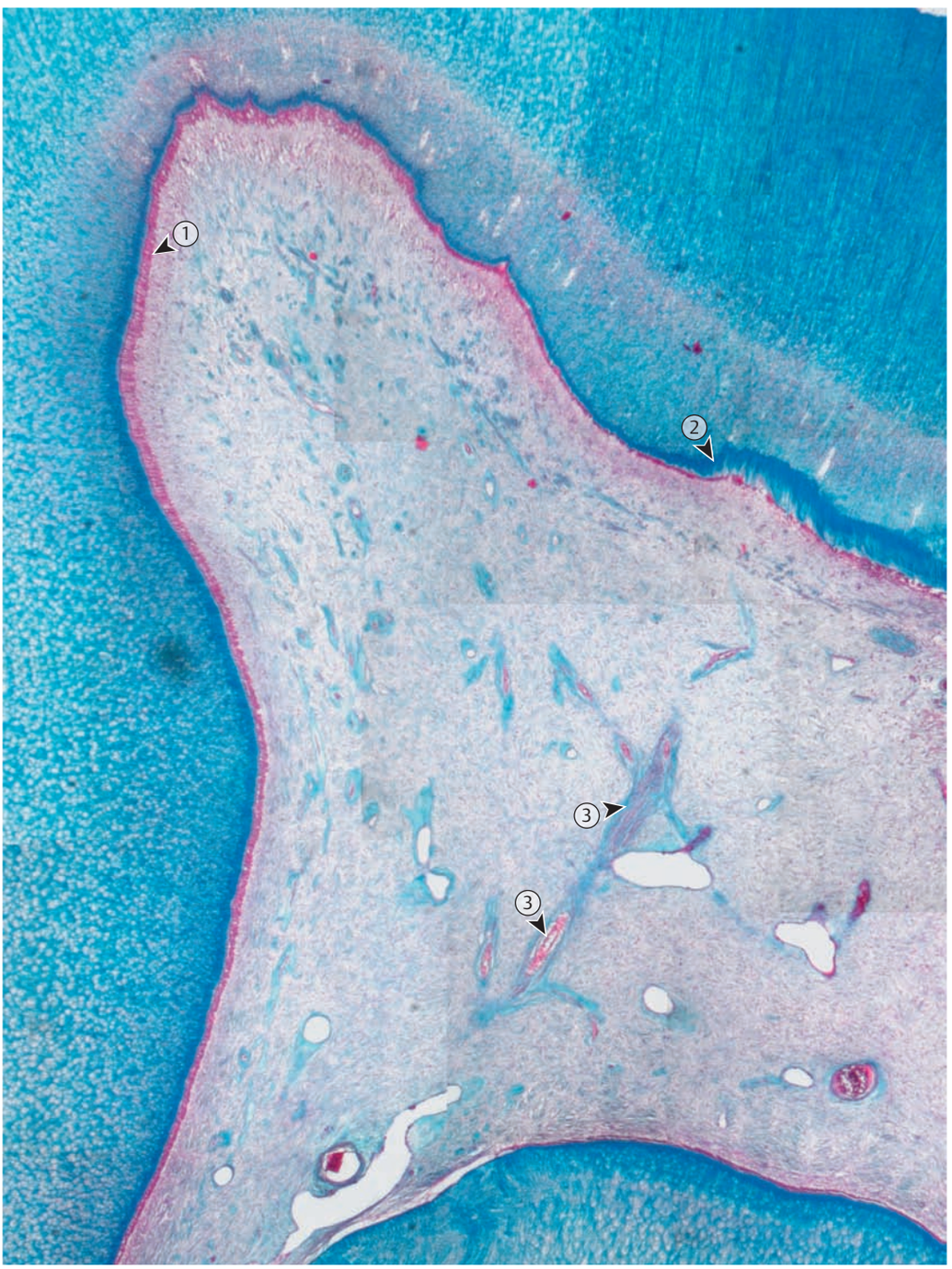
As mentioned in the previous section, the coronal pulp consists of loose reticular connective tissue. At the periphery of the pulp chamber, toward the dentin, the odontoblasts are arranged in a palisade layer, with the odontoblastic processes extending into the dentinal tubules. Between the odontoblasts and the mineralizing dentin, there exists an approximately 20-µm-thick layer of predentin.

In the subodontoblastic layer, there is a complex network of capillaries, which supplies the odontoblasts, and the nerve plexus that innervates the dentin. The nerve fibers that supply the pulpal tissues consist of the Aβ and Aδ fibers and C fibers. The Aδ fibers are rapidly conducting nerve fibers that constitute the subodontoblastic Raschkow plexus and are responsible exclusively for pain perception. The more slowly conducting C fibers are also afferent nociceptive fibers and are located in the central area of the dental pulp.

Numerous arteries and veins are embedded in the loosely structured pulpal connective tissues. The presence of lymphatic vessels in the pulp remains a controversial issue, although relevant morphologic evidence now exists.

1.5 Coronal pulp

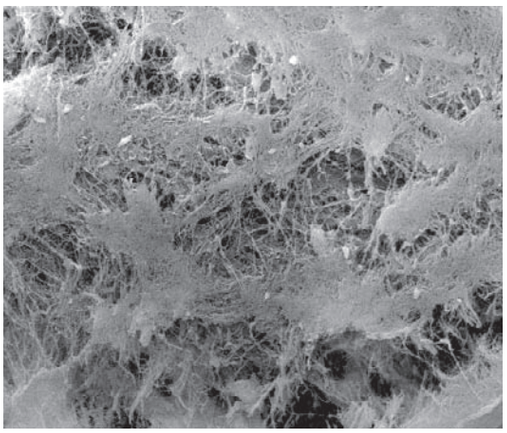
The coronal pulp of a molar. There is a line of demarcation between the newly formed, physiologic secondary dentin and the circumpulpal dentin. The red-stained odontoblasts (**1**) line the entire pulp chamber. The reticular connective tissue of the pulp chamber is characterized by profusely branching vascular elements and nerve fibers (**2** = predentin, **3** = blood vessels).

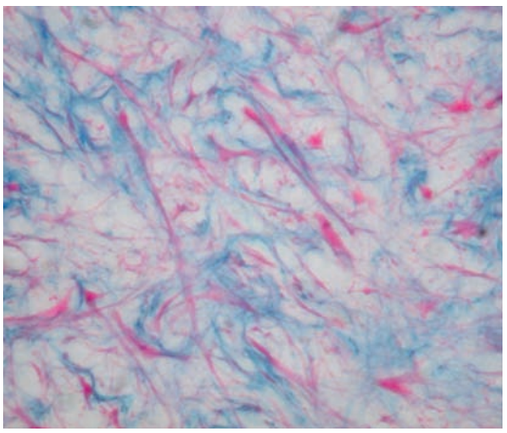


The odontoblasts completely line the pulpal walls. Through tight junctions, gap junctions, and desmosomes, the odontoblasts remain in contact with each other, permitting intercellular exchange of information. The odontoblastic processes extend into the dentinal tubules and stimulate peritubular and intratubular dentin formation.

Toward the center of the pulp chamber, and directly beneath the odontoblasts, are the subodontoblastic vascular and nerve plexus that supply the odontoblasts. The netlike, loosely arranged connective-tissue cells of the pulp chamber provide structural support for the other pulpal tissues. The cells consists primarily of undifferentiated cells from which secondary odontoblasts may derive.

The connective-tissues fibers consist primarily of collagen type I and III. In young pulp tissue, type III argyrophilic fibers predominate, whereas in older pulp tissue the fibers are primarily of collagen type I. The extracellular matrix primarily consists of glycosaminoglycans and proteoglycans. Scattered between the loosely arranged pulpocytes are immunocompetent plasma cells.

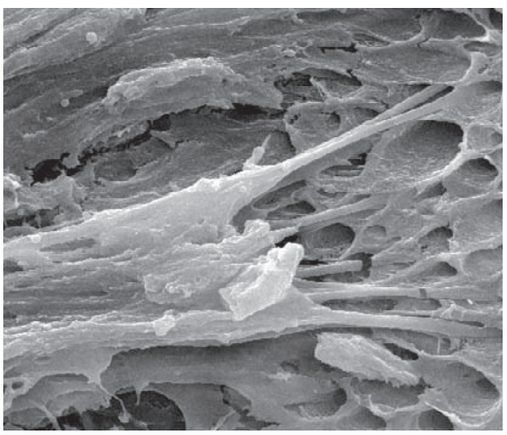


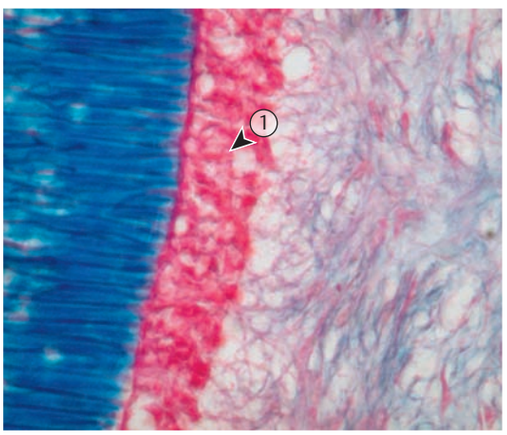


1.6 Coronal pulp

Left: Scanning electron micrograph (SEM) of pulpal cells with abundant intercellular connections.

Right: Loosely arranged pulpal cells exhibiting abundant branching.

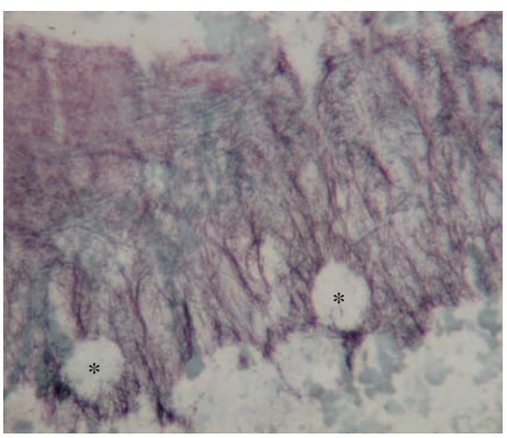


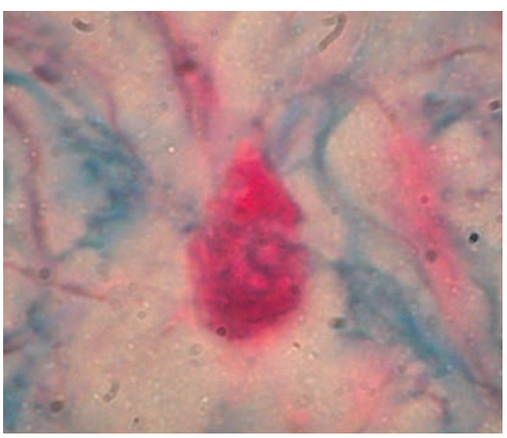


1.7 Odontoblasts

Left: SEM of odontoblastic processes extending into the dentinal tubules.

Right: The odontoblastic layer of the pulpal wall. Note the odontoblastic processes extending into the dentin on the left side and the subodontoblastic capillary plexus on the right side, under the odontoblastic layer (1).





1.8 Nerves and pulpal cells

Left: Neurofibril staining of the nerve plexus around the odontoblasts, with unstained cell bodies of the odontoblasts (*).

Right: Plasma cells in the pulpal tissue.

Root (Radicular) Pulp

In contrast to the histologic appearance of the coronal pulp, the connective tissue in the center of the radicular pulp contains collagenous fibers through which the vascular elements and nerves course. The radicular pulp is also lined by odontoblasts at its border with the dentin.

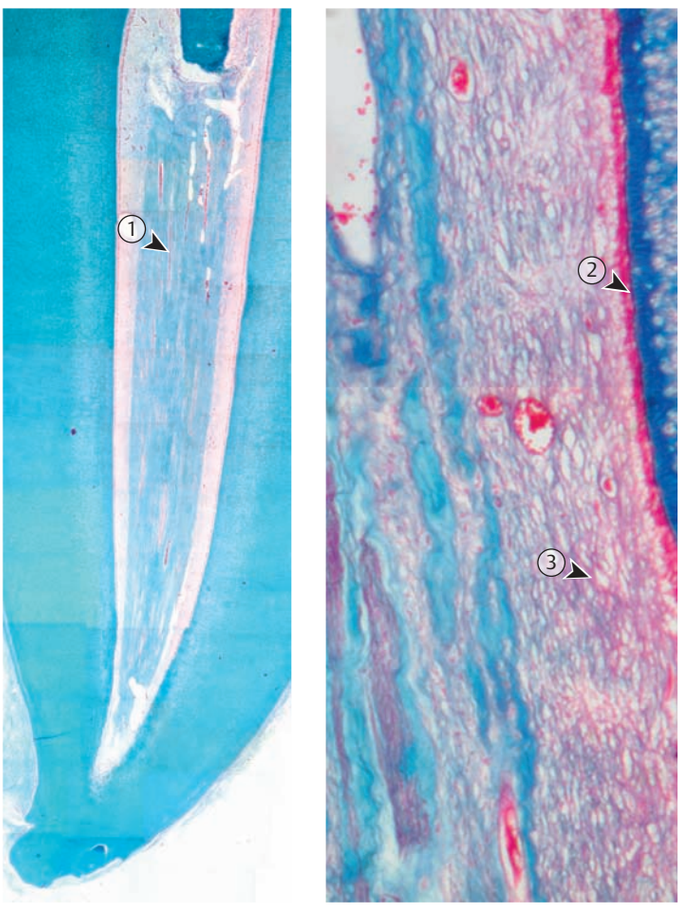
Between the odontoblastic lining and the collagenous connective tissue is a layer of loosely organized connective tissue with finely branching capillaries and nerves running through it.

The blood vessels and nerves of the pulp enter and leave through the apical foramen. The connective tissue of the pulp merges with the periodontal ligament via the apical foramen.

1.9 Radicular pulp

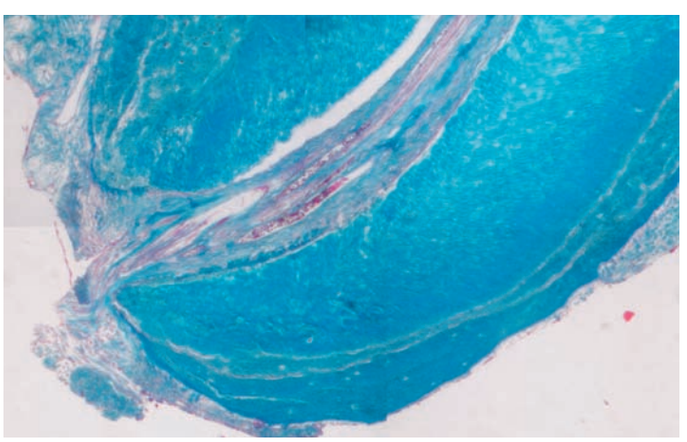
Left: Low-power photomicrograph of the radicular pulp showing the thin odontoblastic layer and loosely structured connective tissue with a core of collagenous connective tissue (**1**).

Right: The thin, red-stained odontoblastic layer (**2**) lining the pulpal wall. To the left, note the loosely organized connective layer (**3**) with scattered vascular elements. Further to the left, is the dense collagenous connective-tissue core with large vessels and nerve fibers.



1.10 Apical foramen

The apical foramen and the entry of vessels and nerves into the pulp. The connective tissue of the pulp merges with that of the periodontal ligament.



2 Pathobiology

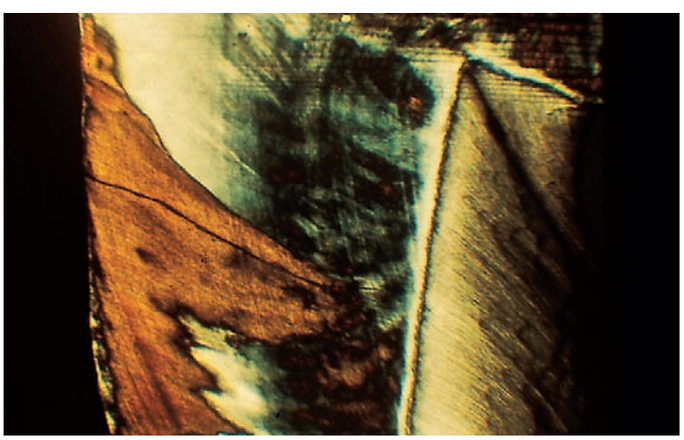
During the past decade, extensive microbiologic, immunologic, and morphologic research studies have shown that any colonization of tooth surfaces by pathogenic bacteria – even transient or superficial colonization – triggers both humoral and cellular host defense responses, regardless of whether the bacterial challenge is incipient (acute) or progressive (chronic).

The breakdown of the complex host defense mechanism is usually temporary, but it destroys the host organism's system of equilibrium, resulting in a disease process. From the endodontic perspective, this biologic equilibrium primarily concerns the balance between calcium and phosphate ion exchange during the continuous process of demineralization and remineralization of enamel and exposed dentin. As long as a disease process is *reversible*, as in the case of initial dental caries, the concepts of "progression" and "remission" exist. Clinical evidence of caries indicates that the acidogenic plaque bacteria are demineralizing more enamel than can be remineralized. In this sense, dental caries is rather a chronic destructive process. Irreversible forms of caries may develop during the superficial stage, with no prospect of remission.

2.1 Initial enamel caries

Left: Extracted tooth with incipient proximal caries below the contact point.

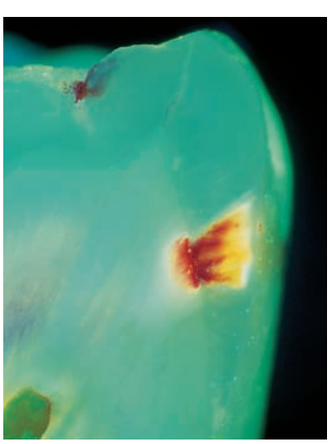
Right: Low-power view of a histologic preparation showing an intact surface layer (10–30 µm thickness). It is sharply demarcated from the body of the lesion. This region also exhibits a clearly reduced mineral content. Relatively large and also small micropores within the adjacent dark zone. Note the initial structural alterations caused by the carious process in the translucent zone.

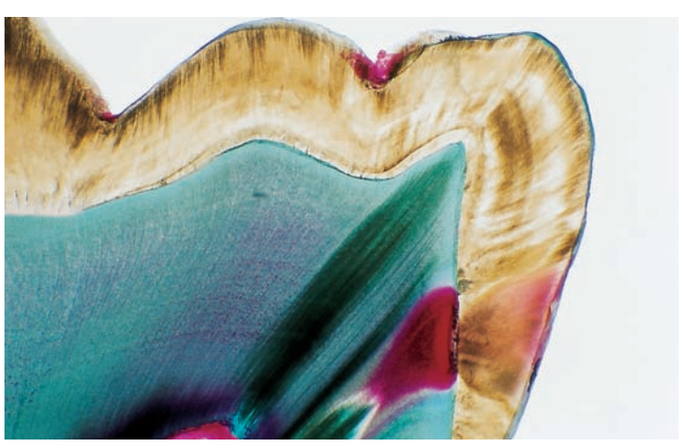


2.2 Initial enamel caries

Left: Clinical appearance of a "brown spot" lesion with cavitation.

Right: The superficial layer is no longer intact. The body of the lesion penetrates the enamel, exhibiting initial dental caries.





2.3 Extension of the carious process

Left: Histologic section through the margin of the lesion also reveals extension of the carious process into the dentin (ultraviolet [UV] light).

Right: Ground section through the center of the lesion reveals clear involvement of the dentin.

Reversible Pulpitis

As the carious lesion starts progressing from the enamel into the dentin, an inflammatory pulpal reaction is initiated. Histologically, neutrophilic granulocytes, lymphocytes, and macrophages begin to appear within the odontoblastic layer. The odontoblastic processes get embedded in a layer of sclerosed dentin, usually with initial formation of peritubular dentin followed by mineralization of the odontoblastic processes (Frank and Voegel, 1980).

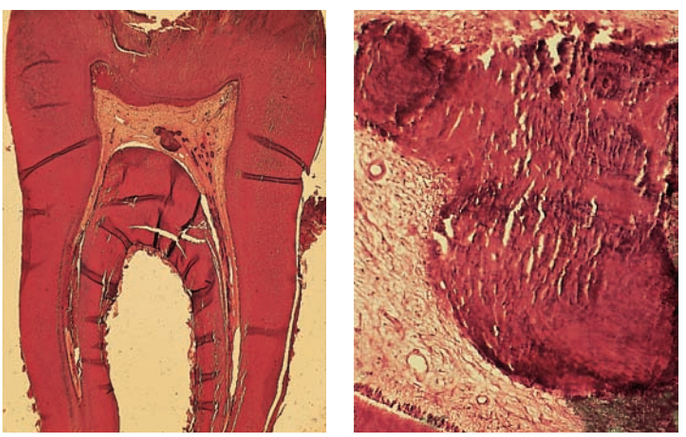
The odontoblastic processes in the upper layers of carious dentin exhibit splayed ends, with membranous fragments within the lumen of the tubule. In this area, there are also large numbers of bacteria (Yamada et al., 1983). If a superficial carious lesion is chronic in nature, in addition to the shrinking odontoblastic border, a small amount of reparative dentin formation will be seen.

Arrested caries in the middle of the dentin (caries media) is characterized by reparative dentin formation, shrinkage of the odontoblastic layer, and cellular infiltration. In the case of active caries, there is massive inflammatory cell infiltration in addition to the damage to the odontoblastic layer.

2.4 Dentinal caries and pulpitis

Left: Slowly progressing dentinal caries leading to the formation of irregular reparative dentin as a protective measure against further toxic influences.

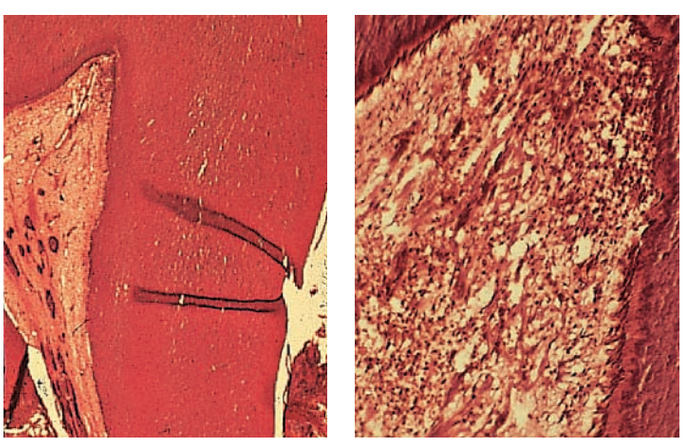
Right: Pulp stones with fibrodentin (atubular dentin), which have been laid down by pulpoblasts (odontblast-like cells) sited away from the center of the pulp as a result of the pathologic irritation.



2.5 Reversible pulpitis

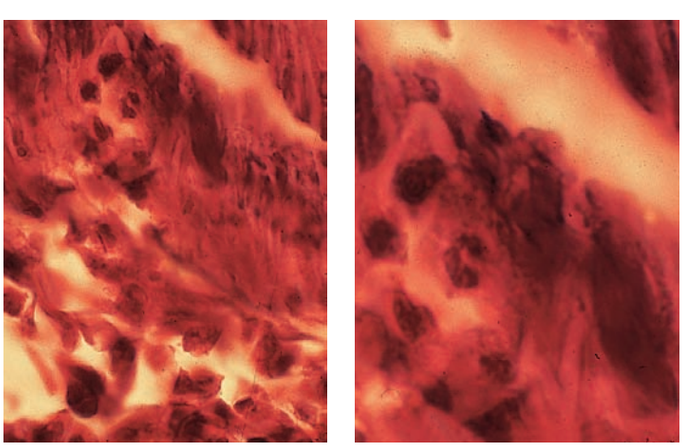
Left: Within the pulp horn, there is no accumulation of hard tissue, and endotoxins can penetrate unhindered into the pulpal tissues.

Right: At the deepest point of the carious lesion, there is obvious disintegration of the odontoblastic layer, and the subjacent capillary plexus is also disrupted, often appearing only as capillary fragments. Lysosomal enzymes induce endothelial cell necrosis, increased vascular permeability, and obvious extravascular edema.



2.6 Reversible pulpitis

While bacteria penetrate the dentinal tubules from the coronal aspect, from the pulpal aspect neutrophilic granulocytes migrate into adjacent tubular orifices, where they release tissue-destroying enzymes.

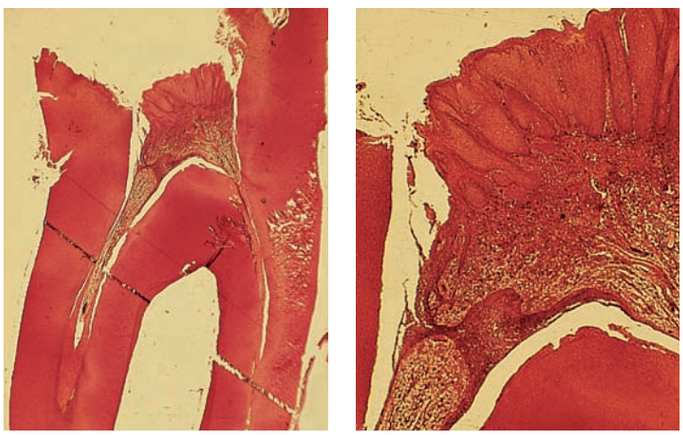


Carious Exposure of the Pulp–"Pulpitis aperta"

If the pulp is exposed by the carious process, an electron photomicrograph will show a large number of dead and necrotic cells within the pulpal tissues. Adjacent to the foci of necrosis will be lymphocytes, plasma cells, and macrophages. Polymorphonuclear leukocytes predominate near the site of exposure, some of which are intact and others partially destroyed, with their organelles scattered in the extracellular matrix.

Micro-organisms are found *within* the neutrophilic granulocytes and macrophages. The endothelial cells of the vascular elements are also damaged, and leukocytes are released from vessels.

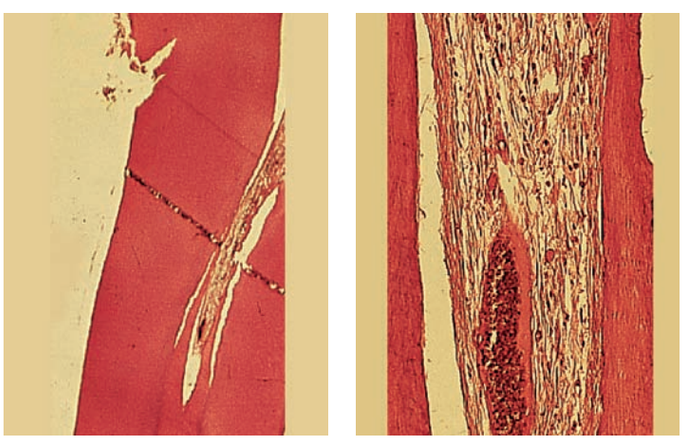
If the carious process results in deep dentinal cavities, inflammation of endodontium occurs within a week, the odontoblastic layer is destroyed and the pulp is infiltrated by neutrophilic granulocytes. Bacteria, necrosis, and cellular destruction occur and reparative (secondary) dentin formation is limited. The injection of a bacterial extract into an open pulp chamber elicits local abscess formation with resorption of bone, cement, and dentin (Stabholz and Sela, 1983).



2.7 Granulomatous open pulpitis ("pulpitis aperta")

Left: Dentin has been penetrated by caries, and bacteria have reached the pulp, resulting in massive accumulation of inflammatory cells. Granulation tissue sprouts the ulcerated pulpal surface and protrudes through the coronal opening.

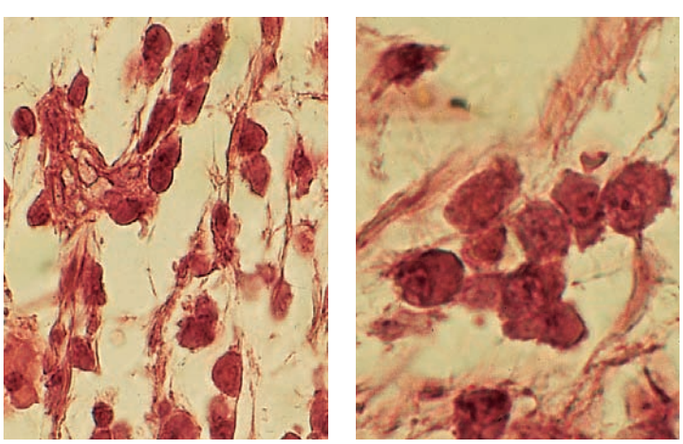
Right: The coronal pulpal tissue has epithelialized, and consists primarily of dense connective tissue. It is rich in collagen fibers, with relatively poor vascularity, and contains numerous nerve fibers that extend into the epithelium, as well as areas of persistent chronic inflammatory infiltration.



2.8 Necrosis of the radicular pulpal tissues

Left: Bacterial infiltration of the coronal pulpal tissues leads to necrosis and tissue destruction. Note the accumulation of polymorphonuclear leukocytes at the root canal orifice, which are differentiated from the mononuclear leukocytes. Granulation tissue is also obvious in the periapical region.

Right: The coronal third of the root canal shows infiltration of inflammatory cells with tissue destruction as well as destruction of the odontoblastic layer.



2.9 Local immune reaction

The inflammatory infiltrate is dominated by monocytes. In addition to lymphocytes, plasma cells can also be seen; the presence of these cells indicates a local immune reaction.

Acute Irreversible Pulpitis

As bacteria penetrate into the dentinal tubules, neutrophilic granulocytes within the pulp migrate toward the orifices of the tubules and engage the bacteria. This process releases lysosomal enzymes and leads to destruction of the pulpal tissues. During the course of the subsequent phagocytosis of the destroyed tissues by polymorphonuclear or mononuclear phagocytes, the cell debris disintegrates, leading to the release of more lysosomal enzymes and further tissue destruction and chemotactic attraction of additional inflammatory cells.

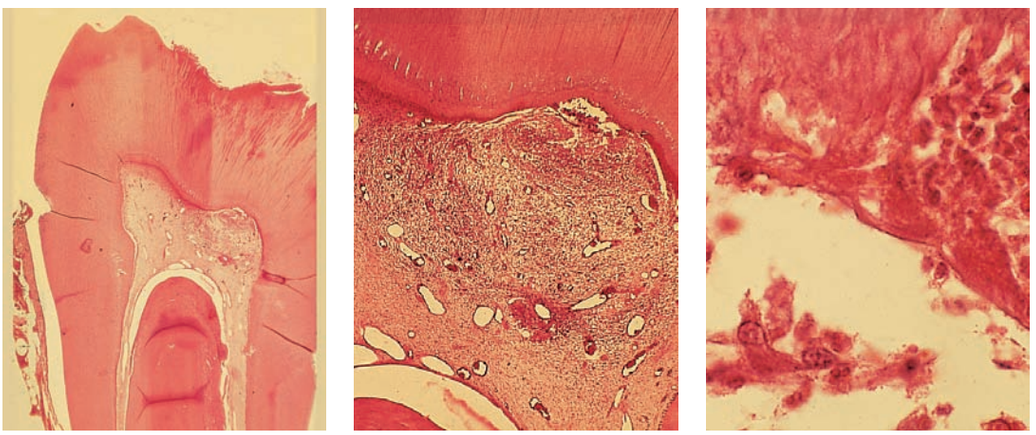
The toxic substances that lead to enhancement of the inflammatory reaction include bacteria, their metabolic by-products, their breakdown products, and finally also the breakdown products of the affected dentin. At this point of the process, a "vicious circle" ensues, manifested by an irreversible pulpitis (Langeland, 1981). Pulp regions near to the necrotic areas are filled with neutrophilic granulocytes that phagocytize the bacteria. This process leads ultimately to the dissolution of entire segments of the pulpal tissue and proceeds in an apical direction (Lin et al., 1984).

2.10 Caries and pulpitis

Left: Advanced caries in the dentin has reached the pulpal tissue under the occlusal fissure, causing circumscribed pulpal inflammation.

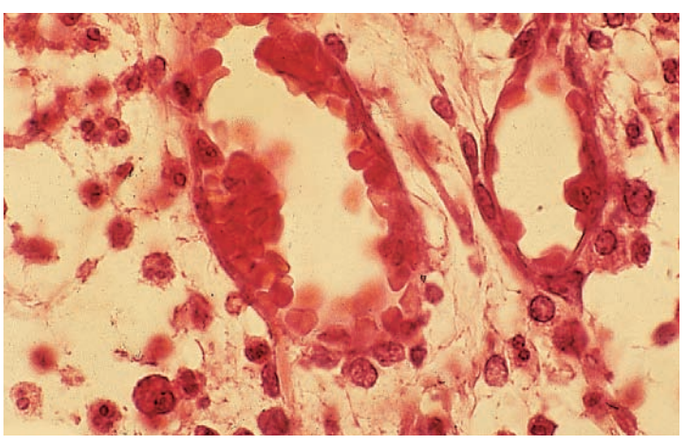
Middle: Death of odontoblasts without formation of reparative dentin, and inflammatory cell infiltration into the adjacent pulpal tissue.

Right: Penetration of bacteria within the dentinal tubules with chemotactic attraction of neutrophilic granulocytes. "Empty spaces" in the subodontoblastic layer represent micronecrotic areas with pus formation and accumulation of polymorphonuclear leukocytes.



2.11 Accumulation of inflammatory cells

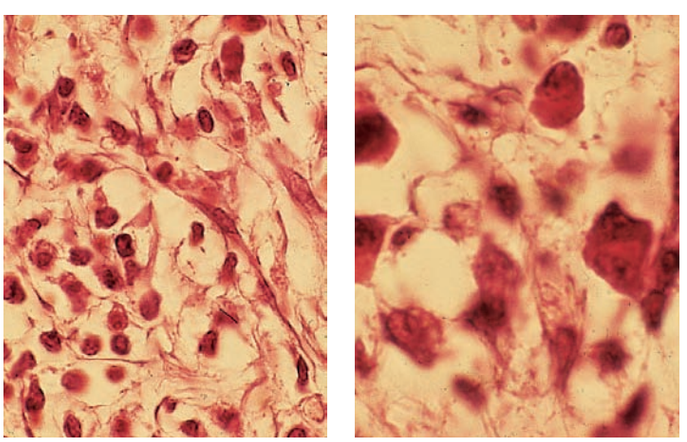
The area opposite the carious destruction of the odontoblastic layer is dominated by neutrophilic granulocytes, which can be identified peripherally and also intravascularly, an expression of a persistent chemotactic irritation. Larger "empty spaces" represent the beginning of tissue necrosis.



2.12 Inflammatory cells

Left: The adjacent tissue contains not only acute polymorphonuclear granulocytes but also chronic mononuclear granulocytes.

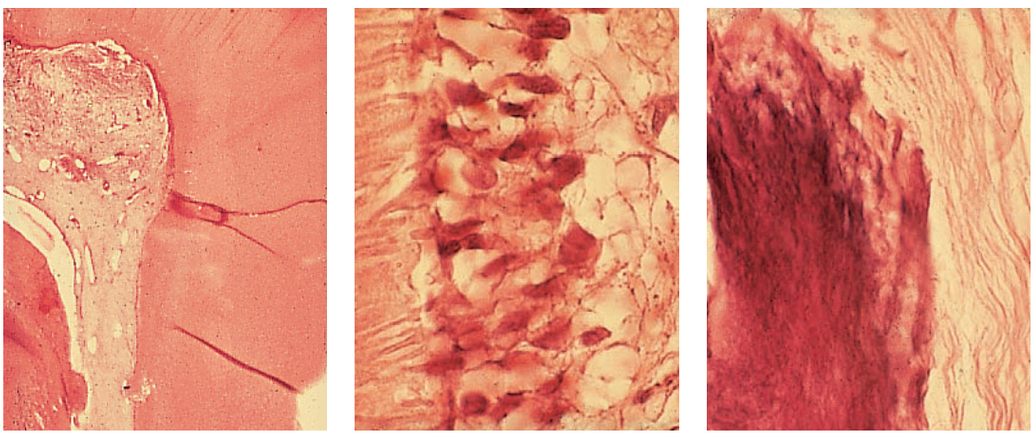
Right: The adjacent tissue exhibits plasma cells and lymphocytes, which can secrete lymphokines as well as other substances. Both migration-inhibiting factors as well as macrophages and dentinoclast-activating factors can be observed. As true lymphotoxins, these factors can also directly induce tissue destruction.



It is important to note, however, that the *histologic* picture of acute inflammation with a preponderance of acute inflammatory cells does not imply that all *clinical* symptoms of acute inflammation will be present. In cases of deep caries (caries profunda), Langeland (1981) established that of 224 teeth with partial pulpal necrosis and severe inflammation, 81 were not associated with clinical pain. Furthermore, Langeland did not find any correlation between the depth of the carious lesion and the occurrence of pain.

It has also been observed that irreversible pulpitis with pulpal necrosis is often accompanied by swelling of the apical periodontal ligament space. The cause for this early periapical reaction appears to be penetration of toxins through intact radicular pulpal tissues. Gram-negative bacteria with external membranes that release endotoxin can elicit a complement reaction. The activation of complement causes release of biologically active peptides, resulting in an increase in vascular permeability and aggregation of neutrophilic granulocytes and macrophages.

Enzymes released during phagocytosis can lead to osseous tissue destruction (Pitts et al., 1982).

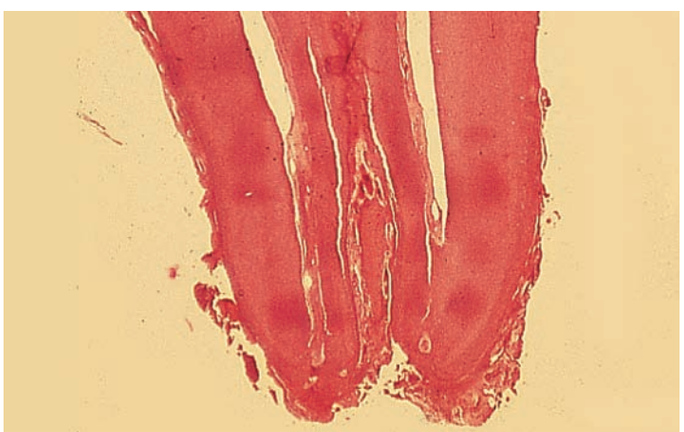


2.13 Absence of inflammation

Left: The low-power histologic section reveals the progress of the carious process and an area of incipient inflammation within the coronal pulp. The root canal pulp is vital and free of inflammation.

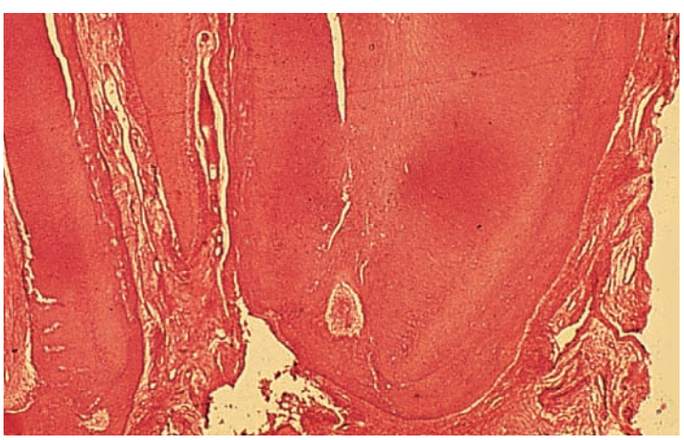
Middle: The odontoblastic layer is intact, also the subodontoblastic area exhibits normal structure. The dentinal tubuli show no irregularity indicating toxic irritation or damage.

Right: A single area of calcification is visible within the root canal. The pulpal tissue is vital and free of inflammatory cells.



2.14 Periapical inflammation

The root canal pulp is free of inflammation, but the periapical region contains granulation tissue. In a radiograph, periapical radiolucency would also be evident.



2.15 Periapical inflammation

The root canal pulp is completely free of inflammatory signs; a few cavitations represent artifacts of specimen preparation. Vacuole formations are a result of delayed fixation of the tissues, excessively short fixation time as well as fixation under pressure, leading to apparent postmortem tissue destruction. These histologic artifacts are not classified as degenerative tissue alterations (Langeland, 1957; Beer, 1983).
Some mononuclear cells can be observed in the periapical region.

Necrosis of Pulpal Tissue

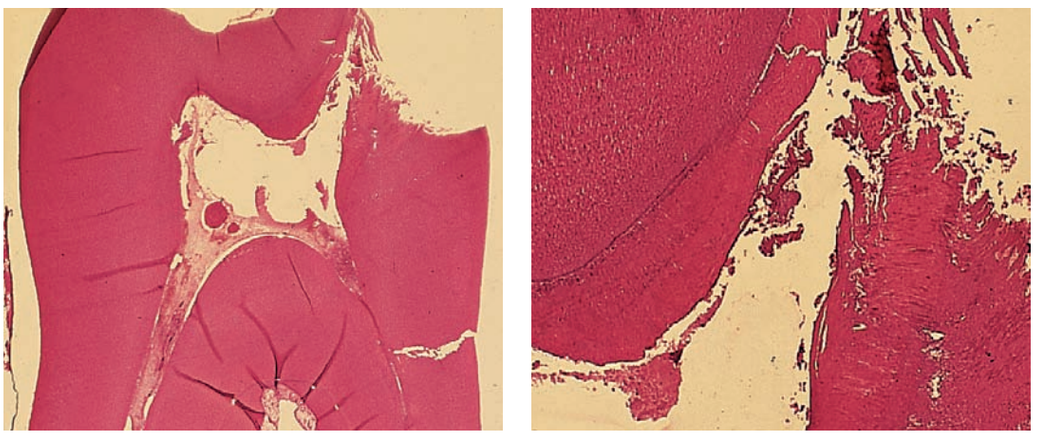
Pulpal necrosis is an irreversible condition characterized by tissue destruction that may occur locally in otherwise vital pulpal tissue in either the coronal or the radicular pulp. Pulpal necrosis is mainly caused by bacterial infection, with the degree of necrosis correlating with the extent of bacterial invasion (Schroeder, 1991).

If an open carious lesion is continuously exposed to saliva, large areas of necrosis with abscess formation will be present after only 6 days, even before penetration of bacteria into the pulpal tissue. According to Lin et al. (1981), if the carious process reaches the pulp with consequent pulpal exposure, the result will always be necrosis of the coronal pulpal tissues. In all 15 teeth examined by these authors, the coronal pulp was partially or completely necrotic; however, only nine teeth had partial or complete necrosis of the radicular pulp. Both acute and chronic inflammatory cells were observed. All the bacteria were found in the coronal pulp in all the teeth and in the radicular pulp in only one-third of the teeth. In 14 of the 15 cases, a periapical radiolucency was also observed.

2.16 Carious pulp exposure and necrosis

Left: The carious process has advanced into the pulp through a coronal opening in the pulpal tissues. The coronal pulp is necrotic and an abscess has formed.

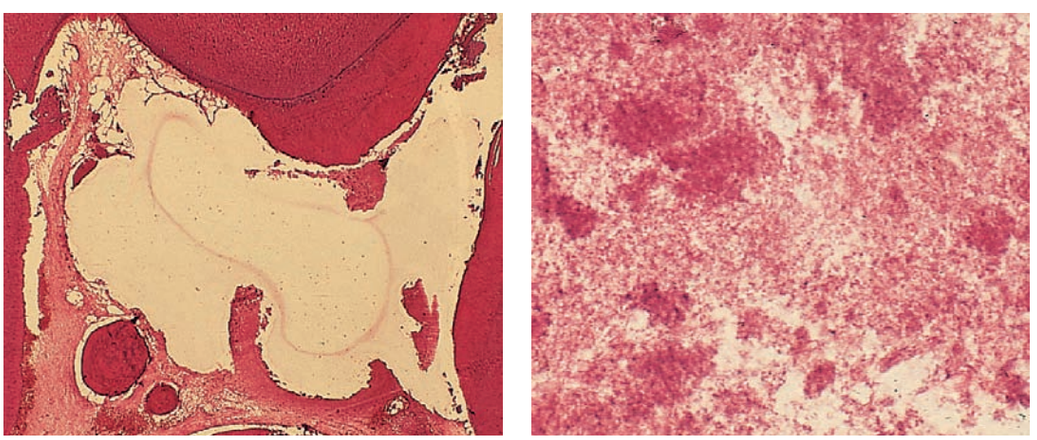
Right: Near the point of carious involvement of the pulp, hard tissue deposits can be seen in the form of tubule-free reparative dentin. The odontoblastic processes were damaged by bacterial toxins, and the result is an inflammatory reaction; following some degree of odontoblastic cell death, reparative dentin has been laid down.



2.17 Tissue necrosis

Left: The coronal pulp contains a large “empty space” consistent with accumulation of pus. The adjacent tissue is necrotic and contains some calcific deposits.

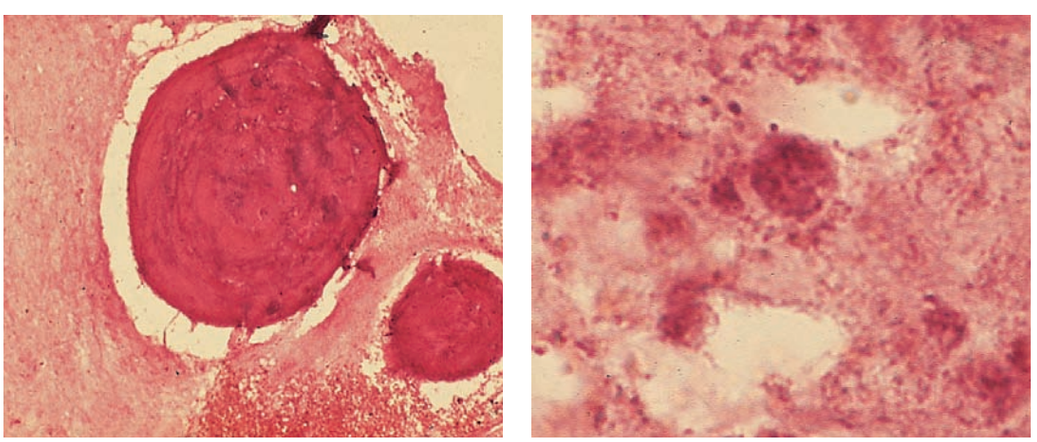
Right: The coronal pulp is completely necrotic. The adjacent tissue also had cell lysis and it was impossible to effectively stain any cell nuclei.



2.18 Tissue necrosis

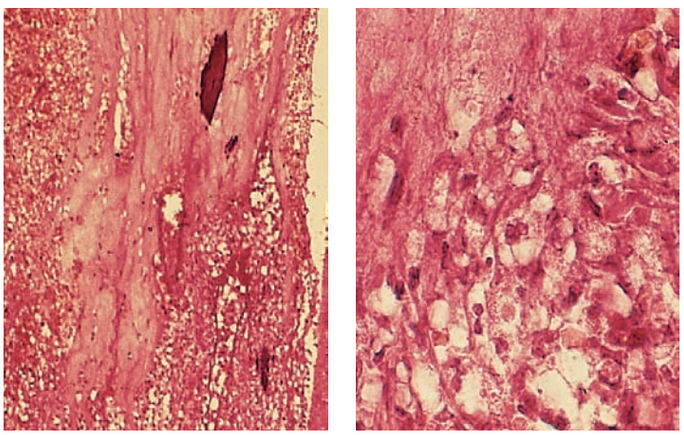
Left: As a result of chronic inflammation, an increased number of diffuse areas of calcifications as well as pulp stones are seen within the pulpal tissues. Such pulp stones are round or oval hard tissue structures formed of fibrodentin, the formation of which is in most cases elicited by external irritation, chronic inflammation, or following cellular death.

Right: Even some inflammatory cells that normally phagocytose and deal with cellular debris have succumbed to the destruction and are no longer clearly visible.



It is not possible to determine the point in time at which the carious process infiltrates the pulpal tissues. The cause of early, severe pulpal destruction is the presence of *bacterial toxins*. High levels of endotoxin are toxic and cause tissue destruction, but lower doses lead to enhanced cellular proliferation and collagen synthesis, indicating a host defense reaction (Pinero et al., 1983).

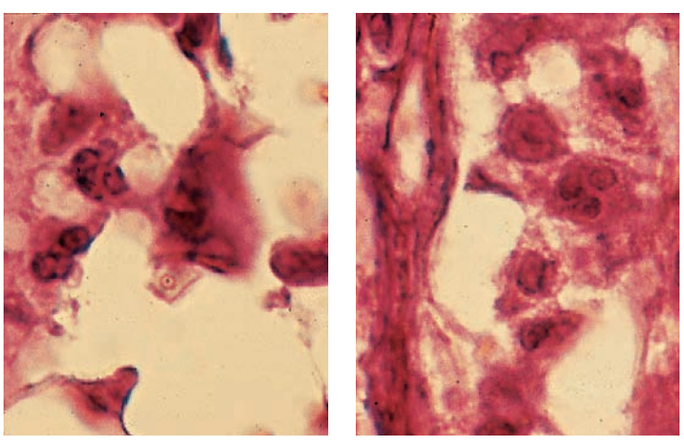
Bacteria cause tissue necrosis; outside the zone of necrosis, the bacteria cannot be observed. Histologically, a normal host defense response is seen as a zone of necrosis surrounded by neutrophilic granulocytes and macrophages, with evidence of active phagocytosis. At the same time, lysosomal products released by the cells destroy the pulpal tissues. It is only in areas of necrosis that bacteria also penetrate into the adjacent dentinal tubules. In their study of apical periodontitis, Lin et al. (1981) found necrosis in the apical radicular pulp in only a third of cases; in six root canals, there was no tissue necrosis, instead, there was vital tissue without bacteria and with only a few inflammatory cells.



2.19 Demarcation of the necrosis

Left: At the transition between the coronal and radicular pulp, the pulpal tissues are necrotic and saturated with inflammatory cells. Further apically within the root canal, no necrosis is observed.

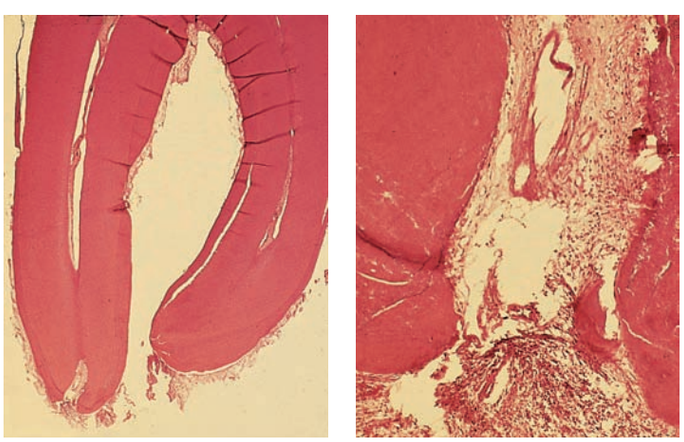
Right: Phagocytic cells engulf bacteria and simultaneously secrete lysosomal enzymes, leading to destruction of vital tissue and the resultant necrosis; this is initially seen histologically as formation of empty spaces with microabscesses.



2.20 Granulocytes

Left: Neutrophilic granulocytes are observed within areas of destroyed tissue.

Right: The dominant cell type is the polymorphonuclear granulocyte (PMNL).



2.21 Periapical inflammation

Left: Early indication of initial periapical inflammation following coronal pulpal necrosis; this is caused by the seepage of endotoxins through the vital radicular pulp tissue.

Right: The apical root canal pulp adjacent to the apical foramen is vital and free of bacteria. The periapical periodontal tissues are clearly infiltrated by leukocytes.

Bacterial Infection in the Root Canal

Only a limited number of the approximately 300 species of bacteria forming part of oral microflora are found in infected root canals. Between one and 12 different species have been isolated, however, the numbers of individual bacteria have been estimated to be between 100 and more than 10 million.

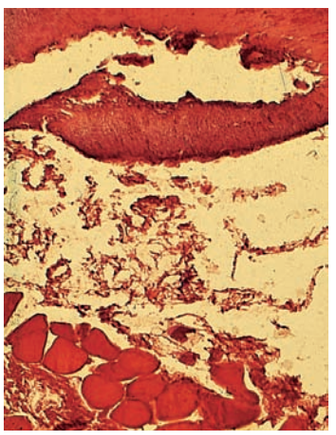
There is a direct correlation between the size of a periapical lesion and the number of bacterial species isolated, as well as the total bacterial load. Thus, Sundqvist (1992) isolated more strains of bacteria in root canals of teeth with larger carious lesions.

The dynamics of a bacterial infection in the root canal was demonstrated in a series of animal experiments by Fabricius et al. (1982). In carious teeth contaminated by bacteria from the saliva, in which the cavities were carefully and completely sealed, facultative anaerobic bacteria were much more frequently observed in the initial time period of up to 3 years. After 6 months however, the total number of bacteria decreased to under 2% of the original number although the proportion of strict anaerobic bacterial strains increased. It was proposed that a selective mechanism within the root canal promoted the development of a specific microbiologic environment.

2.22 Caries penetration into the pulpal tissues

Left: The progression of the carious process has led to exposure of the pulpal tissues and tissue necrosis within the coronal pulp as well as in parts of the radicular pulp.

Right: This section through an area of necrosis within the crown shows tissue destruction.



2.23 Necrosis within the root canal and apical periodontitis

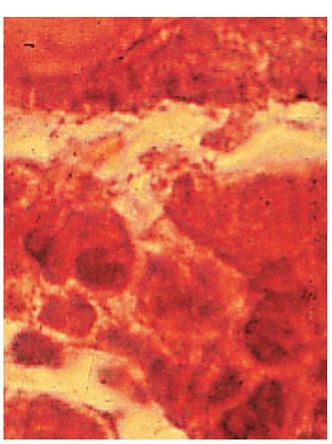
Left: The radicular pulp is largely necrotic with periapical inflammation and buildup of granulation tissue.

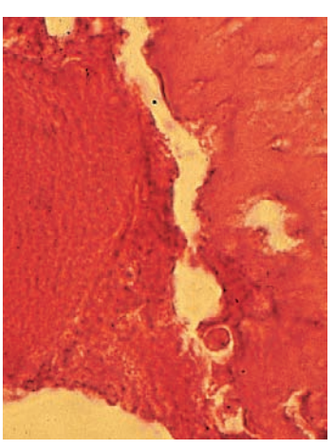
Right: Necrosis of the root canal pulp; the space on the left side is a histologic artifact. A necrotic pulp without bacterial infection does not lead to the formation of a periapical lesion. Apical periodontitis will only develop in the presence of bacteria (Möller et al., 1981).

2.24 Pulp obliteration

Left: Obliteration of structures within the root canal only occurs as a result of the inflammatory reaction, with formation of irregular, reparative dentin. The adjacent tissues exhibit accumulation of neutrophilic granulocytes.

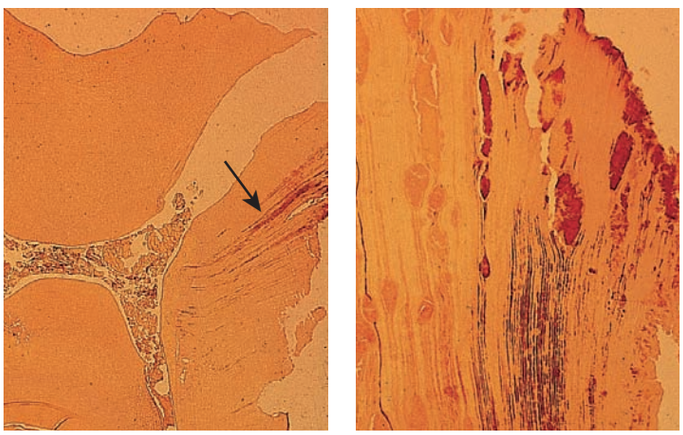
Right: Note the pulp stones.





Symbiotic relationships often exist among bacteria in an infected root canal. For example, Sundqvist et al. (1989) frequently found *Fusobacterium nucleatum* together with *Peptostreptococcus micros, Wolinella recta, Porphyromonas endodontalis*, and *Selenomonas sputigena*. Numerous factors can influence the bacterial colonization of the root canal. Some bacterial metabolic by-products can be used by other bacteria as nutritional substances (Loesche, 1968). Bacteriocin, which is released by some microorganisms, can inhibit the growth of other bacteria (van Winkelhoff et al., 1987).

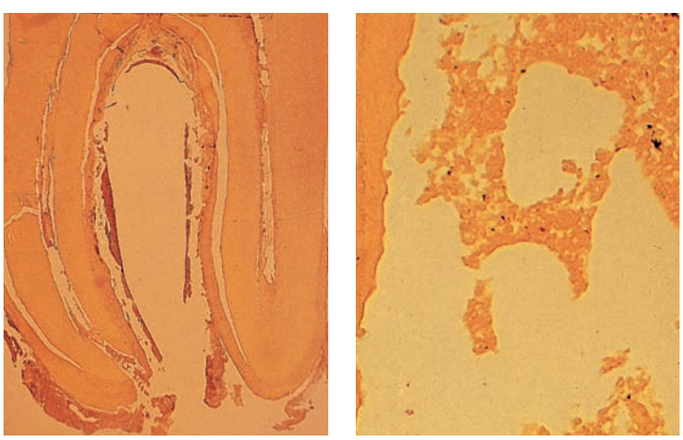
Bacteria within an infected root canal release enzymes that can enhance the pathogenicity of the bacteria. In this way, immunoglobulins of the host organism can be inactivated, for example by *P. asaccharolyticus* and *endodontalis. P. intermedia* and *gingivalis* degrade complement factor C3. Both are important opsonins for the phagocytosis of these bacteria during the host response process. *P. gingivalis* can simultaneously degrade the proteinase inhibitors important in maintaining the integrity of the tissue surrounding the infection (Carlsson et al., 1984).



2.25 Bacteria within dentin

Left: The histologic photomicrograph permits differentiation between non-infiltrated (yellow) and infiltrated tissues (red, arrow). The coronal pulp contains bacteria, also found within the dentinal tubules and the pulpal tissue.

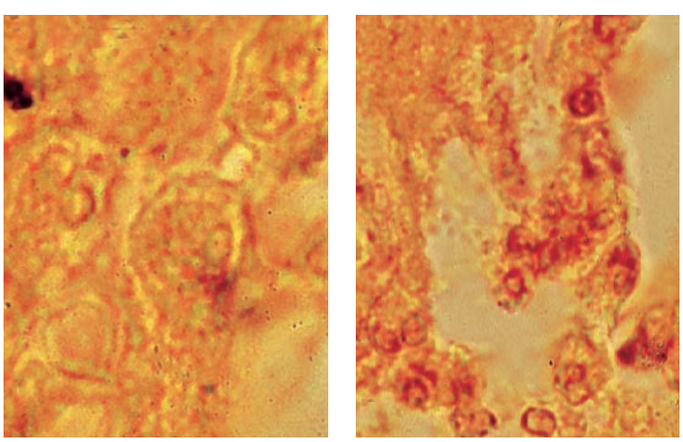
Right: The bacteria have caused destruction of dentin, resulting in the formation of recesses or caverns. The latter are generally filled with bacteria and connective-tissue matrix remnants.



2.26 Bacteria within the root canal

Left: The tissue within the root canal is necrotic and periapical accumulation of inflammatory cells is clearly visible. The specimen, however, does not permit identification of specific bacterial species.

Right: The coronal pulp as well as the coronal aspect of the root canal pulp contains aggregates of bacteria.



2.27 Intracellular bacteria

Left: No bacteria can be detected histologically within the area of periapical inflammation.

Right: At a higher magnification, in the middle third of the root canal, intracellular bacteria within neutrophilic granulocytes are evident.

Acute Apical Periodontitis

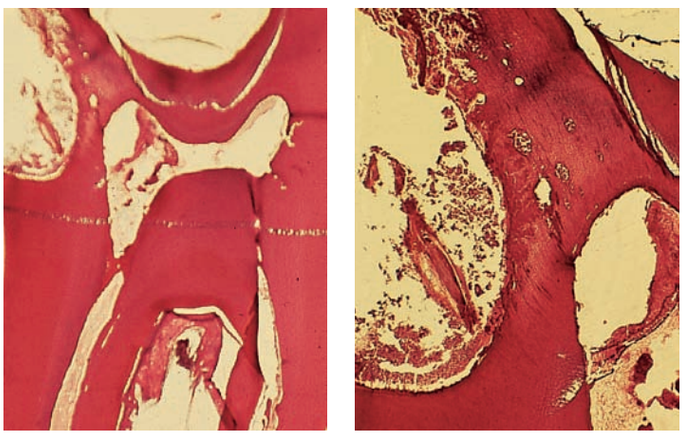
A periapical lesion occurs only in the *presence of bacteria within the root canal*. This was demonstrated in 1965 by Kakehashi et al. in their studies on germ-free rats. The teeth of these animals developed periapical inflammation only after bacterial inoculation. If the teeth were simply drilled and the pulp exposed to the germ-free oral milieu there was no development of periapical periodontitis. Similar results were reported by Möller et al. (1981) in monkey teeth. Following necrosis of the pulpal tissues, no periapical lesions developed if the access cavity was completely sealed.

Nair (1987) studied 31 periapical lesions. In every case, bacteria could be detected within the root canal, both dispersed as well as adherent to the dentinal wall, and within the dentinal tubules. In 18% of the cases studied, bacteria were detected in the periapical tissues; one case clearly had actinomycosis. In three other lesions, the bacterial plaque appeared to adhere to the dentinal wall and progress toward the center of the apical periodontitis, eliciting a circumscribed but pronounced area of necrosis as well as an acute inflammatory cell response.

2.28 Progression of the carious process

Left: Despite a thin layer of dentin, penetration of bacteria and their components through the dentin has led to pulpal inflammation and necrosis.

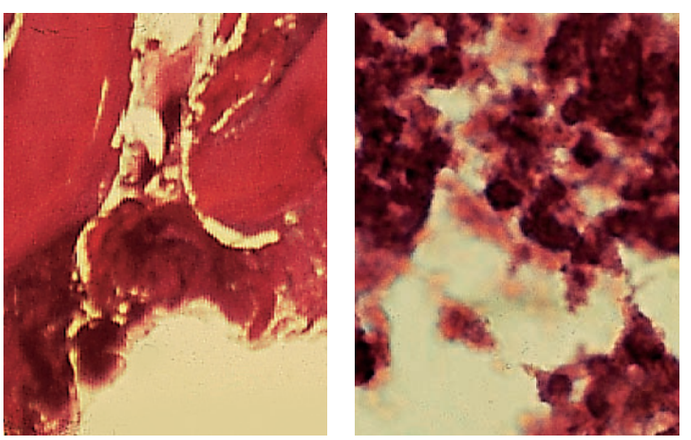
Right: Carious destruction, the bacterial irritants have elicited a reaction in the adjacent tissue, resulting in tissue necrosis.



2.29 Apical periodontitis

Left: Acute apical periodontitis has developed at the periapical foramen.

Right: In the areas adjacent to the necrotic tissue, the pulpal tissues are infiltrated with neutrophilic granulocytes that phagocytose the bacteria and also release lysosomal agents that enhance the inflammatory reaction.

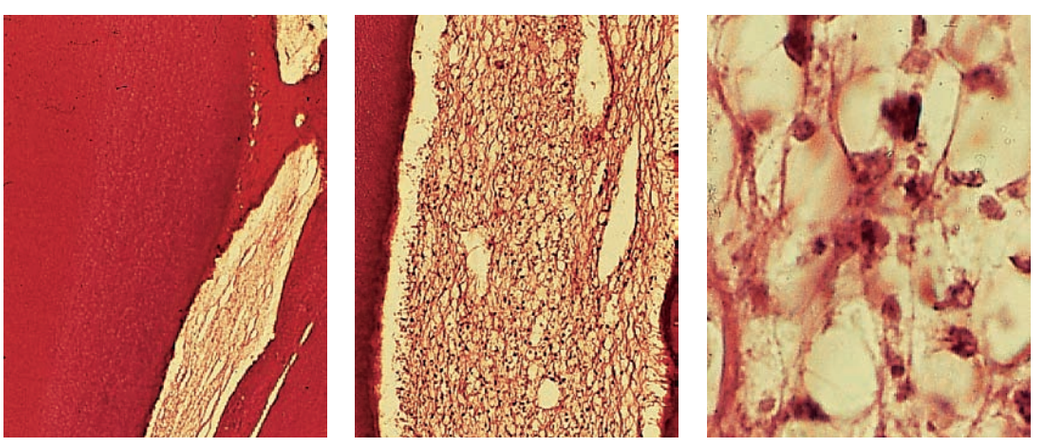


2.30 Necrosis and lysis

Left: Bacteria and areas of necrosis are observed in the entire coronal pulp and also in the adjacent root canal pulp.

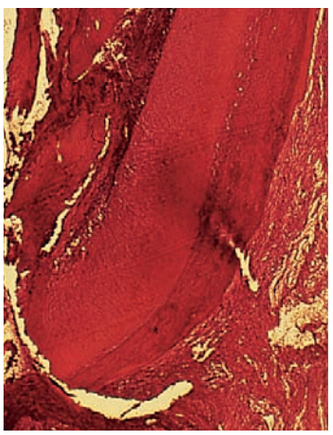
Middle: The pulpal necrosis is characterized by cell death and tissue destruction, which may be localized or involve the entire radicular pulp.

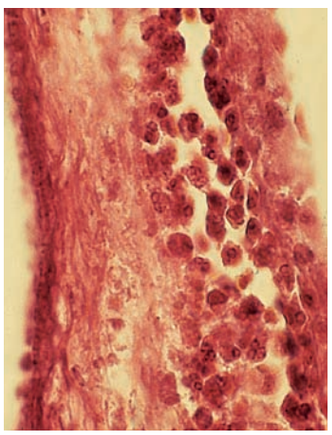
Right: Necrotic tissue containing some intact cells and some dead inflammatory cells. The result is destruction and dissolution of the entire pulpal soft tissue, a process that may extend beyond the root apex.



Acute apical periodontitis is characterized *histopathologically* by an exudate of polymorphonuclear granulocytes and macrophages limited to the widened periodontal ligament space. Macrophages play a dominant role in the degradation of immune and complement complexes, while neutrophilic granulocytes dominate in the defense mechanisms against nonhost substances. Macrophages attract bacterial antigens and enhance the immunogenic potential of the host. The result is further massive infiltration of neutrophilic granulocytes, accompanied by tissue necrosis and dissolution, leading to abscess formation.

In the case of the periapical abscess, the necrotic tissue around the root apex is saturated with bacteria, surrounded by a wall of neutrophilic granulocytes (Nair and Schroeder, 1985). The microbial flora around the periapical abscess is described as "polymicrobial," and includes at least five bacterial species. Gram-negative, anaerobic rods, and peptostreptococci predominate. Periapical abscesses contain black-pigmenting bacterial species, which play an important role in the etiology of periapical lesions. Van Winckelhoff et al. (1985) found *P. intermedia* in 63% and *P. endodontalis* in 53% of their cases.

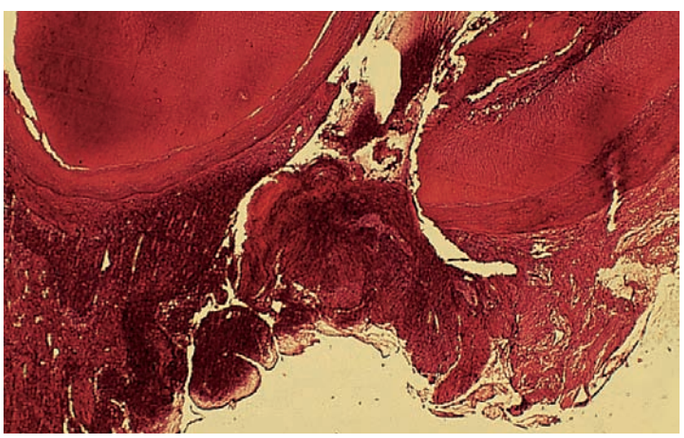




2.31 Inflammation within the apical root canal pulp

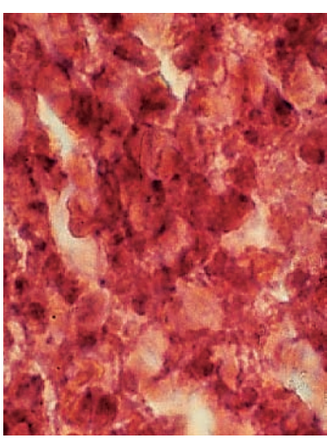
Left: The apical third of the root canal pulp is partially necrotic and infiltrated by inflammatory cells; the toxins released during the inflammatory process elicit an inflammatory reaction at the periapical region. Histologic sections taken during this process will reveal the remaining vital areas of pulpal tissue.

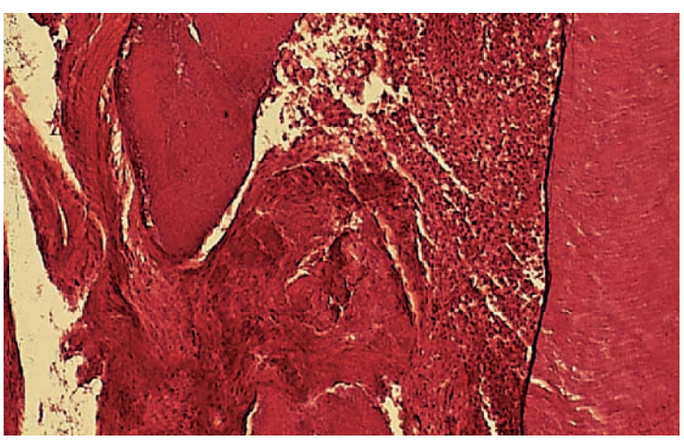
Right: This is a section from the coronal zone of necrosis that is separated from the adjacent pulpal tissues by an intervening layer of neutrophilic granulocytes.



2.32 Acute apical periodontitis

In the periapical region, note the accumulation of inflammatory cells and also resorption lacunae within the dentin and the appearance of dentinoclastic as well as osteoclastic activity. The transition zone within the root canal contains significantly fewer inflammatory cells.





2.33 Inflammatory cells

Left: In addition to neutrophilic granulocytes, there are eosinophils, plasma cells, foreign body giant cells, and mast cells. A characteristic feature is the continuous infiltration of inflammatory cells.

Right: This magnified histologic section of the periapical region reveals the accumulation of inflammatory cells, surrounded by collagen-rich granulation tissue.

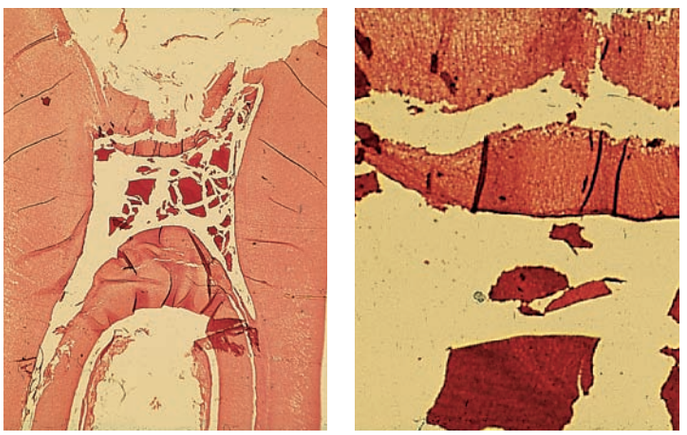
Chronic Apical Periodontitis

Following induction of apical periodontitis in rat molars, the histologic appearance between days 7 and 20 consisted of an active phase with severe *osseous destruction* and a subsequent chronic phase with relatively mild increase in the lesion. Morphometrically, at 15 days as well as up to 90 days, lymphocytes dominated the field (50%–60% of all cells), followed by polymorphonuclear leukocytes (25%–40%), macrophages, plasma cells, and fibroblasts. T-helper cells were predominant in the acute lesion, whereas T-suppressor cells were predominant in the chronic lesion. The former cells play an important role in osseous destruction while the latter stabilize the lesion, rendering it more chronic. T-helper cells induce the production of an interferon, which stimulates macrophages to produce the bone resorption factor interleukin (IL)-1. A bone-resorbing cytokine is produced, and T-helper cell factors stimulate the formation of antibodies and immune complexes. High IL-1 concentrations prevent new bone formation via the inhibition of protein synthesis by osteoblasts (Stashenko et al., 1994).

2.34 Necrosis

Left: From the coronal aspect, carious exposure of the roof of the pulp chamber has led to pulpal necrosis.

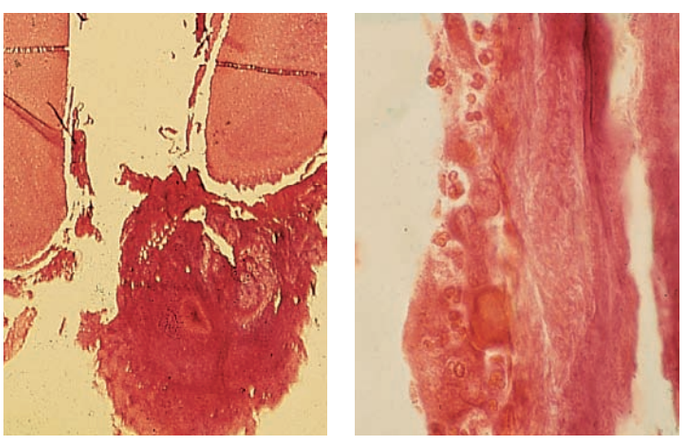
Right: Magnified histologic section of the area of the necrotic coronal pulp.



2.35 Chronic periapical lesion

Left: The periapical region has a large encapsulated accumulation of inflammatory cells; in the center of this periapical lesion are numerous encapsulated empty spaces.

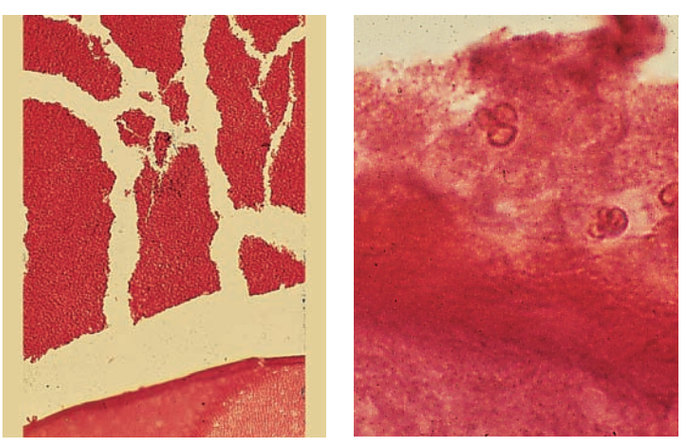
Right: The tissue within the root canal is necrotic and contains primarily neutrophilic granulocytes, some of which have lysed and released additional tissue-destructive enzymes.



2.36 Necrosis of the coronal pulp

Left: The tissue in the transition zone between coronal and radicular pulp has disintegrated. The “cracks” in the area of necrosis are histologic artifacts.

Right: The granulocytes are chemotactically attracted by bacteria and their toxins, and phagocytose cellular debris as well as foreign bodies. In this process they die, and also destroy any adjacent, still-intact tissue. Nerve fibers remain for the most part intact even in the face of severe inflammation and tissue necrosis.

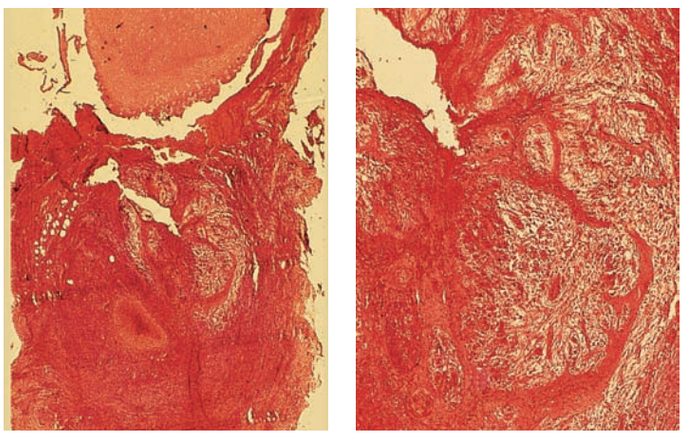


Clinically, chronic apical periodontitis is asymptomatic. There is a direct correlation between the size of the periapical lesion and the amount of bacterial infiltration and tissue necrosis within the root canal. Teeth with small periapical lesions continue to react positively to standard sensitivity tests, but in those with larger lesions no reaction can be expected (Lin et al., 1984).

The main features of *chronic periapical lesion* are (Schroeder, 1991):

- There is lymphocytic and plasma cell infiltration.
- Granulation tissue may be seen.
- Epithelial rest cells of Malassez may proliferate.
- A connective-tissue capsule may develop, consisting of fibroblasts and collagen fiber bundles.

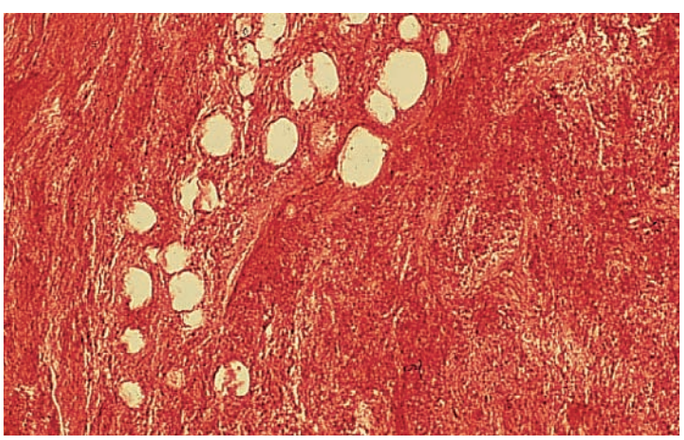
The increase in antibody concentration in acute lesions and a reduction following endodontic treatment demonstrates that preparation of the root canal and the removal of bacterially infected tissues in cases of chronic apical periodontitis is the treatment of choice (Kettering and Torabinejad, 1984).



2.37 Tightly attached periapical granulation tissue

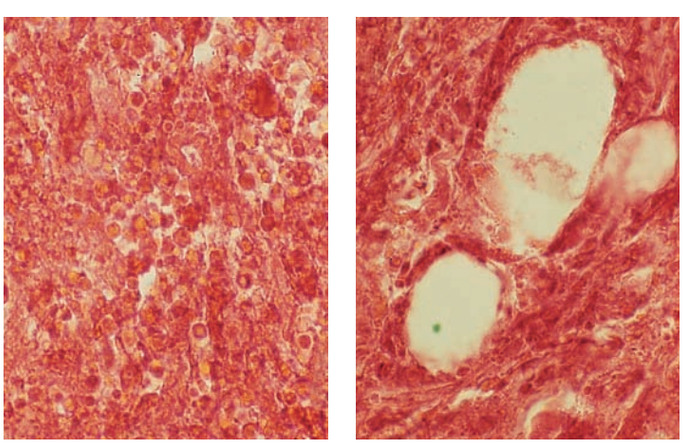
Left: A chronic periapical lesion surrounded by a dense connective-tissue capsule, and containing mast cells, fibroblasts, and collagen fiber bundles. In the center is a focal infiltrate of mononuclear inflammatory cells including lymphocytes, plasma cells, and macrophages.

Right: The magnified histologic section shows strands of epithelium immediately adjacent to the root apex, and also distributed in a somewhat bizarre fashion within the central zone of the periapical region.



2.38 Periapical granulation tissue

The photomicrograph shows granulation tissue with fibroblasts and mononuclear inflammatory cells. In addition, 30%–60% of cases have encapsulated microabscesses in the center of the lesion, visible as cavities at the top of the photomicrograph.



2.39 Microabscesses

Left: The magnified histologic section shows strands of epithelium with a mononuclear cellular infiltrate. Epithelial rests of Malassez are difficult to discern.

Right: This highly magnified section shows several encapsulated and apparently dormant microabscesses, which may represent the incipient phase of a future cystic epithelium. Strands of epithelium penetrate and proliferate within the granulation tissue and surround it in an arcade or netlike pattern.

Radicular Cysts

The “true” radicular cyst is defined as a zone of chronic periapical inflammation circumscribed by an epithelial lining around a closed cavity.

The cyst develops from the floor of an area of chronic apical periodontitis. In the first of the three phases of development—initiation—dormant epithelial rest cells of Malassez begin to proliferate. During the second phase, an epithelial-lined central cavity develops, and in the third phase—as a result of osmotic and resorption-stimulating factors—there is formation of a true cyst (Nair et al., 1996).

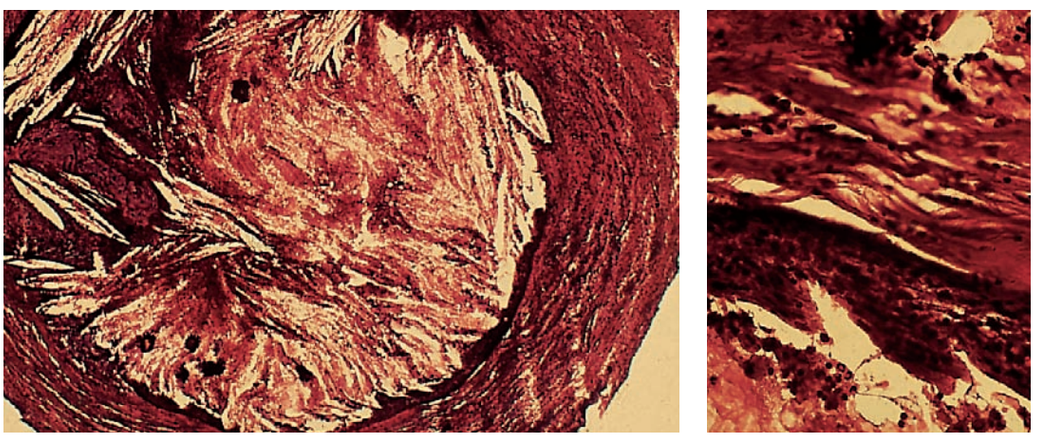
An established radicular cyst has a connective-tissue capsule, a subepithelial zone of inflammatory infiltrate, the epithelial cyst wall, and the cyst lumen. In addition to necrotic epithelial cells, this lumen contains cholesterol crystals, as well as inflammatory cells and remnants of the resorbed osseous tissues.

The wall of the cyst is made up of a multilayered squamous epithelium, consisting of granulocytes, macrophages, and lymphocytes. The subepithelial zone contains T lymphocytes and B lymphocytes, as well as plasma cells (Schroeder, 1991).

2.40 Structure and components

An established radicular cyst containing cholesterol crystals and surrounded by the epithelial cystic wall and the subepithelial zone with infiltration of inflammatory cells within the cystic lumen. The connective-tissue capsule contains fibroblasts and collagen fiber bundles and is firmly attached to the periapical periodontal fibers.

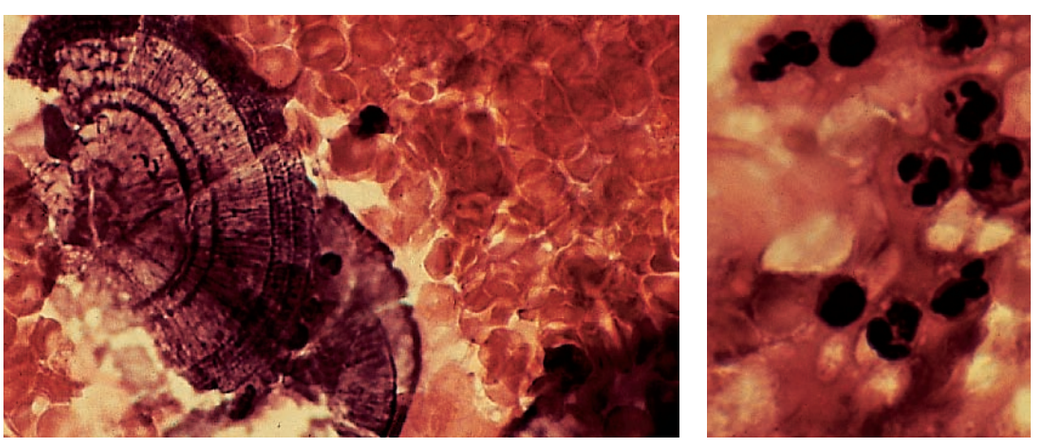
Right: The epithelial cystic wall consists of multilayered squamous epithelium devoid of a stratum corneum, and approximately 20 to a maximum of 50 cells thick.



2.41 Content of the cystic lumen

Remnants of osseous lamellae within the cystic cavity illustrate the capacity of the cystic tissue to resorb hard tissues.

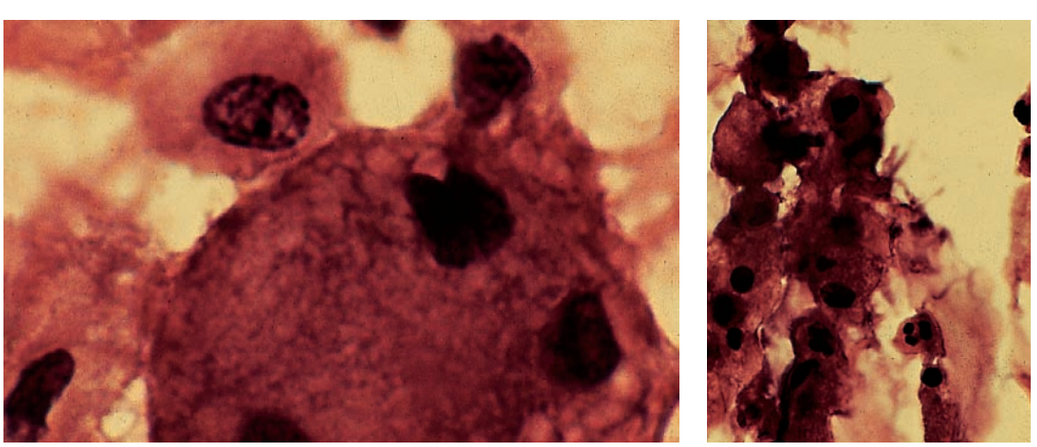
Right: The organic constituents within the cystic lumen form a cystic fluid that is difficult to differentiate, with inclusion of neutrophilic granulocytes and some lymphocytes that indicate infection and acute exacerbation of the inflammatory process.



2.42 Content of the cystic lumen

Multinuclear giant cells represent a possible foreign-body reaction as well as osteoclastic activity; adjacent plasma cells produce antibodies, primarily IgG and IgA, and less often IgM and IgE.

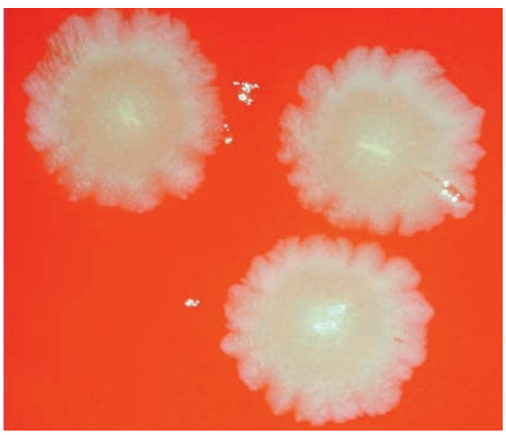
Right: Lymphocytes are most frequently T cells, and less often B cells (ratio of 3:1).

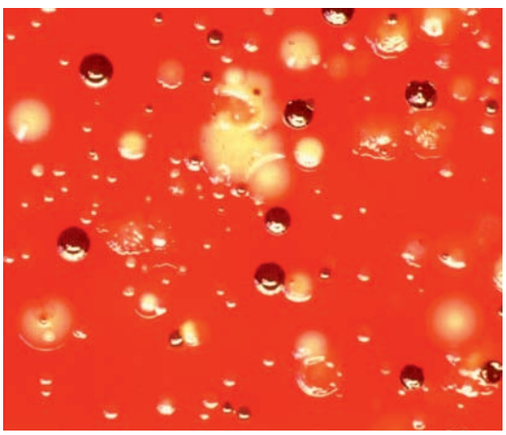


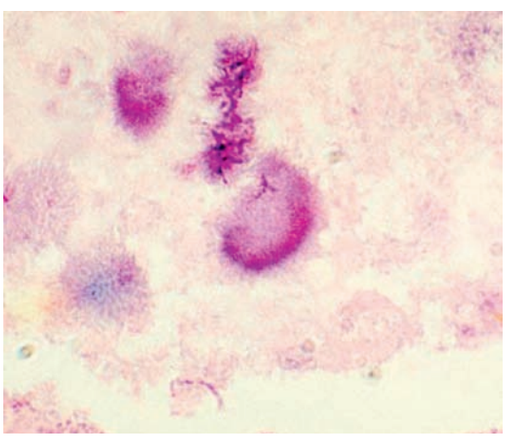
3 Endodontic Microbiology

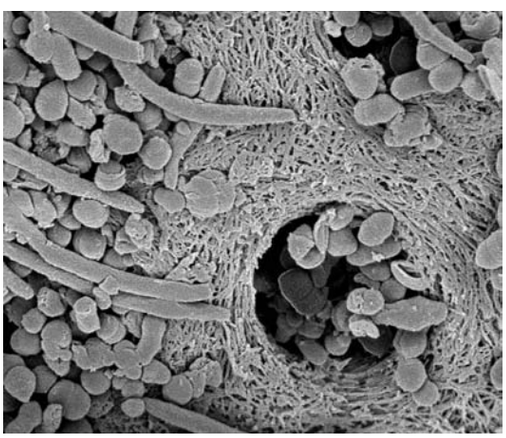
Since the pioneering studies of Miller (1894), there has been continuous interest in the microbiologic aspects of endodontic diseases. Almost all clinical situations requiring endodontic treatment have a microbiologic etiology or may later develop a microbiologic component. Subsequently, to ensure the best possible chance of success in treatment, the dentist must be familiar with the key aspects of endodontic microbiology:

- the role of microbes in the etiology and pathogenesis of the various diseases involving the tooth root canal system;
- the effect of the treatment procedures on the microbial infection;
- methods of preventing reinfection of the root canal.









3.1 Detection of bacteria

Primary apical periodontitis: infection by anaerobic bacteria. Anaerobic and microaerophilic bacteria are the key microbial components of primary apical periodontitis. These images show some of the most important microorganisms causing endodontic disease.

Above left: *Fusobacterium nucleatum* colonies.

Above right: *Prevotella intermedia* (dark brown) and *Porphyromonas gingivalis* (light brown) colonies together with colonies of other bacteria from an infected root canal.

Below left: Histologic preparation showing bacterial colonies in periapical actinomycosis.

Below right: Scanning electron microscopic image of bacteria penetrating into dentinal tubules.

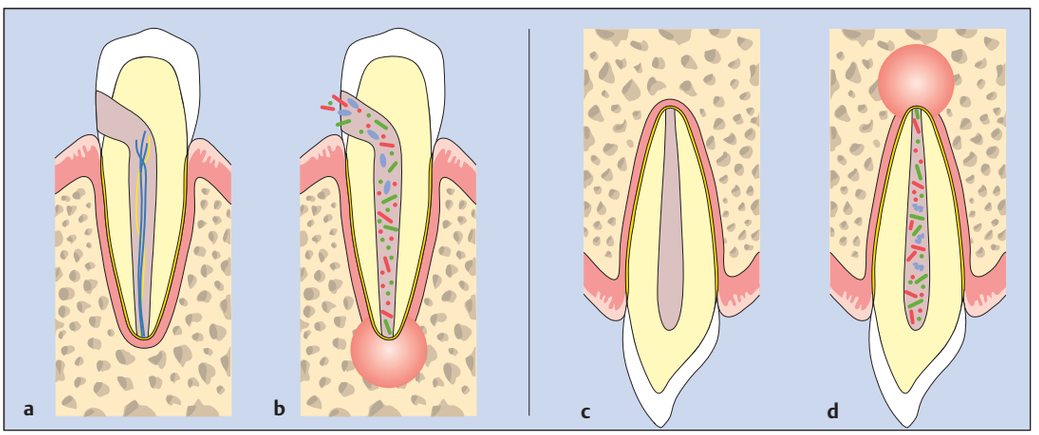
Etiology of Apical Periodontitis

The connection between microbes and apical periodontitis (AP) is well established. Using gnotobiotic rats (rats raised in a sterile environment), Kakehashi et al. (1965) were the first to demonstrate the indisputable causal relationship between periapical inflammation (apical periodontitis = lesion of endodontic origin [LED]) and the presence of microbes in the root canal. Compared with normal rats, gnotobiotic animals with pulps exposed to the oral cavity and saliva with no bacteria developed no periapical disease.

Kakehashi and coworkers' results were verified and refined further by Bergenholtz (1974) and Sundqvist (1976), who showed that intact necrotic human teeth exhibited apical periodontitis *only* if bacteria were present in the root canal, whereas necrotic teeth with a sterile root canal exhibited no periapical pathoses.

3.2 Classic studies of periapical periodontitis

Kakehashi et al. (1965) demonstrated that pulpal exposure without bacteria did not lead to pulpal necrosis in gnotobiotic rats (a). However, as soon as experimental animals came into contact with rats with normal oral bacterial flora, radiographs revealed pulpal necrosis and periapical lesions shortly after (b). Sundqvist (1976) studied intact but necrotic teeth with and without periapical lesions. Periapical lesions could only be detected in teeth in which bacteria could be identified in the root canals and subsequently cultured (c, d).

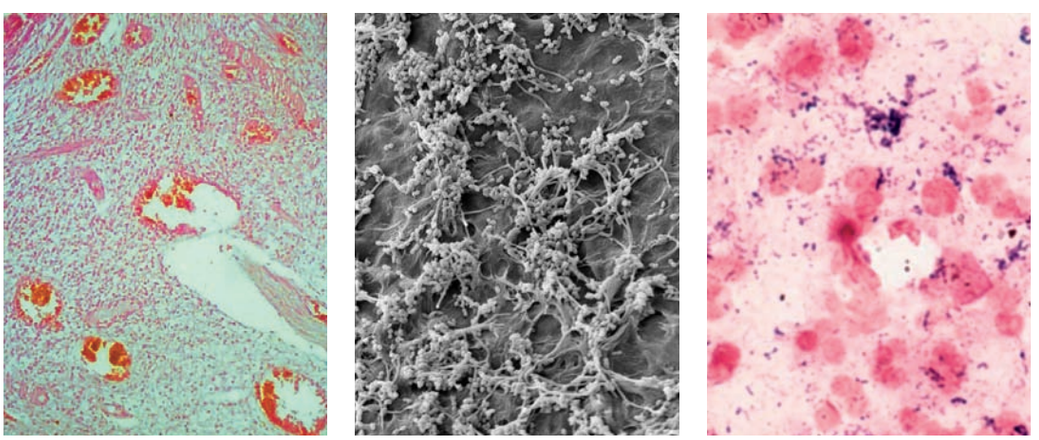


3.3 Bacterial infection is the cause of apical periodontitis

Left: Inflamed area within the coronal pulp. Although bacteria have not yet progressed into the pulp, an initial inflammatory reaction appears.

Middle: The biofilm within the root canal contains bacteria (cocci and rods) in dense aggregates showing various morphotypes.

Right: Gram-stained biopsy from the necrotic root canal of a tooth with associated AP; note the relatively even distribution of numerous leukocytes (red) Gram-positive cocci, and rod-like bacteria (blue).



3.4 Radiographic appearance

Left: The radiolucent periapical lesion in this necrotic tooth indicates the presence of an infection in the necrotic root canal.

Middle: AP in an apparently intact tooth. The etiology in such a case is usually trauma, which leads to necrosis. Bacteria penetrate through microscopic canals and lateral canals, or as bacteremia into the root canal.

Right: A fractured H file in a tooth with a partially filled root canal; the file extends far beyond the apex. The radiograph shows no evidence of an apical lesion.

Pathogenesis of Pulpitis and Apical Periodontitis

The initial immunologic reactions in the development of pulpitis occur in response to bacterial antigens released from the advancing bacterial front within the carious lesion. These antigens are first "examined" by the antigen-detecting/antigen-presenting cells (APCs) of the pulp.

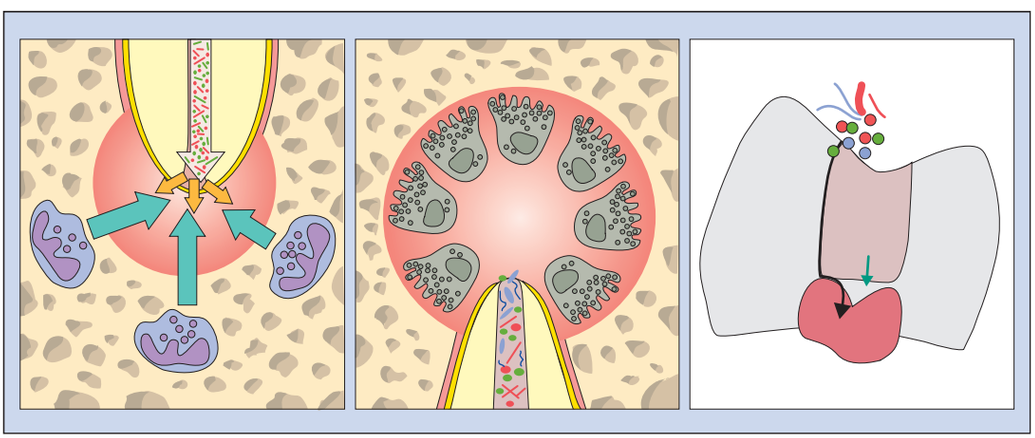
Dendritic cells are the main APCs in the pulp and macrophages (except histiocytes) which have major histocompatibility complex (MHC) class II molecules on their cell surface (Jontell et al., 1998). The class II molecule is a gene product of MHC and present foreign material (e.g., antigens) to T cells in the regional lymph nodes for recognition.

Following this, memory T cells are released into the circulation in the tissues, including the pulp, where they contribute to the secondary immune response. When the microbial cells in the advancing front of the carious lesion enter the pulp, infiltration of polymorphonuclear leukocytes and other inflammatory cells such as T memory cells and plasma cells can be observed.

Immunologic defense reactions anywhere in the body cause local tissue destruction, and the pulp is no exception. Microabscesses and focal necrosis can sometimes be seen in the pulp even before the carious lesion (and the microorganisms) invades the pulp.

With progression of caries and increasing antigen challenge, the area of necrosis increases in size and eventually the entire coronal pulp becomes necrotic. It is only at this stage that the root canal(s) of the affected tooth will have become infected.

Acute inflammatory responses to advancing infection in the periapical area involve numerous cells of the host inflammatory response system, and are induced by endogenous mediators such as prostanoids, kinins, and neuropeptides. Interleukin-1 and prostaglandins are key mediators of periapical bone resorption by osteoclasts (Stashenko et al., 1998).

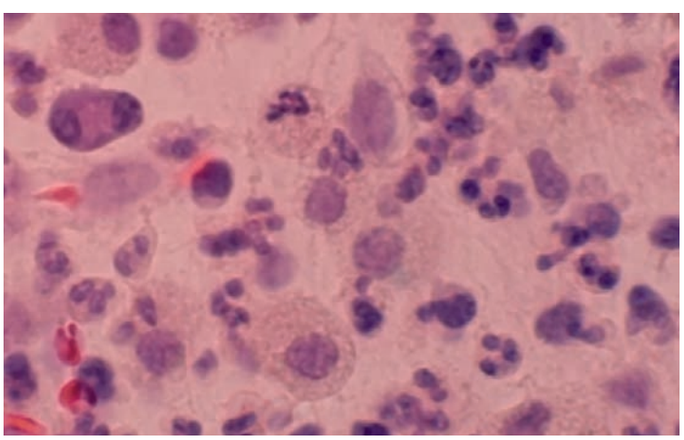


3.5 Immune reaction

Left: Stability in the periapical region: The immune defense cells inhibit an invasion of microorganisms from the necrotic root canal.

Middle: In a case of chronic AP, the osseous tissue is resorbed by multinucleated osteoclasts that are activated by an immunologic cascade.

Right: The pulp tolerates the chemical assault of numerous filling materials (green arrow). Microbial leakage through the space between tooth and root canal filling material (black arrow) often lead to pulpal irritation.



3.6 Apical periodontitis

Left: A radiograph showing a deep carious lesion in a maxillary premolar. The maxillary second premolar also has a periapical lesion representing AP.

Right: Granulocytes, plasma cells, and lymphocytes are apparent in this histologic section of this periapical region of a tooth with chronic AP.

Microbiota in Primary Apical Periodontitis

Chronic Apical Periodontitis

Chronic apical periodontitis is a symptom-free apical inflammation caused by microbes within the necrotic root canal. There is usually polymicrobial infection, dominated by obligate anaerobic bacteria (Moller et al., 1966; Bergenholtz 1974; Kantz and Henry, 1974; Sundqvist, 1976, 1994; Heimdahl et al., 1985; van Winkelhoff et al., 1985, 1988; Haapasalo et al., 1986a, b; Sundqvist et al., 1989; Haapasalo 1993; Siqueira et al., 2001; Fouad et al., 2002; Khemaleelakul et al., 2002; Munson et al., 2002; Siqueira and Rocas, 2003, 2004a).

The number of different species per case is relatively small, typically two to eight species, with rarely more than 15 species in one tooth. The most frequent isolates are *Dialister pneumosintes (Bacteroides pneumosintes), Tannerella forsythensis (B. forsythus), Prevotella* spp., *Porphyromonas* spp., *Fusobacterium* spp., *Treponema* spp., *Campylobacter rectus (Wolinella recta), Micromonas micros (P. micros), Eubacterium* spp., *Bifidobacterium* spp., *Actinomyces* spp., *Propionibacterium* spp., *Lactobacillus* spp., and *Streptococcus* spp. Most of the above genera are strictly anaerobic, some include both anaerobic and facultative anaerobic species and strains, while streptococci are facultative bacteria. *E. faecalis* is less often observed in primary apical periodontitis than in posttreatment endodontic disease (Peciuliene et al., 2001; Rocas et al., 2004). Bacteria most frequently isolated from primary apical periodontitis lesions are shown in Figs. 3.7 and 3.8.

3.7 Bacterial groups and genera

This table presents a comprehensive list of bacteria that are routinely isolated from apical periodontitis lesions.

Bacteria most often detected in endodontic infections

Anaerobic bacteria

Gram-negative cocci	Gram-negative rods	Gram-positive cocci	Gram-positive rods
• Veillonella	• Prevotella • Porphyromonas • Bacteroides • Dialister • Fusobacterium • Filifactor • Campylobacter • Selenomonas • Treponema	• Micrococcus • Peptostreptococcus • Finegoldia	• Eubacterium • Pseudoramibacterium • Mogibacterium • Bifidobacterium • Clostridium • Propionibacterium • Lactobacillus • Olsenella • Atopodium • Actinomyces

Facultative anaerobic and aerobic bacteria

Gram-negative cocci	Gram-negative rods	Gram-positive cocci	Gram-positive rods
• Neisseria	• Actinobacillus • Haemophilus • Eikenella • Capnocytophaga • Enterobacter • Klebsiella • Escherichia • Citrobacter • Pseudomonas • Xantomonas • Proteus	• Streptococcus • Gemella • Enterococcus • Staphylococcus • Micrococcus	• Propionibacterium • Lactobacillus • Actinomyces • Bacillus • Corynebacterium

Bacteria most commonly found in apical periodontitis before endodontic treatment

Gram-negative anaerobic rods	Gram-positive anaerobic cocci	Gram-positive anaerobic rods	Gram-positive facultative cocci
• Prevotella intermedia • Prevotella nigrescens • Prevotella buccae • Prevotella oris • Prevotella oralis • Prevotella denticola • Dialister pneumosintes • Dialister invisus • Porphyromonas gingivalis • Porphyromonas endodontalis • Fusobacterium nucleatum • Campylobacter rectus • Campylobacter gracilis • Selenomonas spp.	• Micrococcus micros • Peptostreptococcus anaerobis • Finegoldia magna	• Eubacterium spp. • Filifactor alocis • Propionibacterium acnes* • Actinomyces viscosus* • Actinomyces israelii • Actinomyces naeslundii* • Lactobacillus spp.*	• Streptococcus anginosus • Streptococcus intermedius • Streptococcus constellatus • Streptococcus mitis

* Most species are microaerophilic or facultative anaerobes

Acute Apical Periodontitis

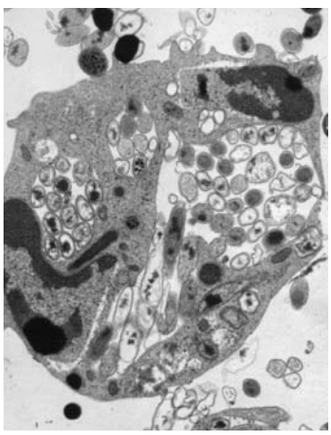
Clinical signs and symptoms of acute apical infection include pain, swelling, abscesses with or without a sinus tract. Increased tenderness to percussion/palpation is also typical in the acute phase. The microbiologic factors related to symptoms are both qualitative and quantitative. Sundqvist (1976) found that the probability of pain was greatly increased when at least six different species were found in the same canal. A relationship has also been suggested between clinical symptoms and the presence of certain black-pigmented *Prevotella* and *Porphyromonas* species (Sundqvist, 1976; Haapasalo et al., 1986a). However, anaerobic bacteria are seldom related to long-lasting symptoms.

In addition to *P. gingivalis* and *P. endodontalis*, there are also other bacteria more associated with symptomatic AP than with symptom-free cases. These include *P. buccae, F. nucleatum, E. yurii, P. magnus, P. dentalis, T. denticola,* and *T. socranskii* (Griffee et al., 1980; Heimdahl et al., 1985; van Winkelhoff et al., 1985; Haapasalo, 1986; Haapasalo et al., 1986a, b; Yoshida et al., 1987; Sundqvist et al., 1989; Hashioka et al., 1992; Siqueira and Rocas 2004b; Sakamoto et al., 2006). Species typically found in samples taken from endodontic abscesses include *F. nucleatum, P. gingivalis, P. endodontalis,* and *P. intermedia* (Heimdahl et al., 1985; van Winkelhoff et al., 1985). However, acute infections routinely respond well to high-quality endodontic therapy.

Gram-negative anaerobic rods
• Prevotella buccae • Prevotella dentalis • Porphyromonas gingivalis • Porphyromonas endodentalis • Fusobacterium nucleatum
Treponema spp.
• Treponema socranskii? • Treponema denticola?
Gram-positive anaerobic rods
• Eubacterium yurii?
Gram-positive cocci
• Finegoldia magna?

3.8 Bacterial species in apical periodontitis

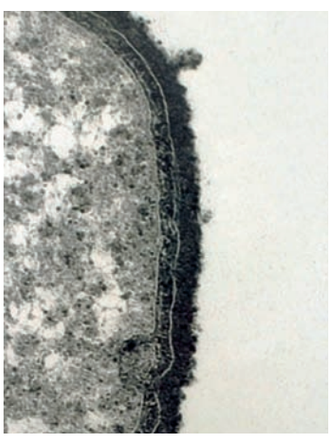
In addition to *P. gingivalis* and *P. endodontalis*, other bacteria are also found in cases of painful AP, and not in symptom-free lesions. These include *P. buccae, F. nucleatum, E. yurii, Peptostreptococcus magnus,* and *P. dentalis, T. denticola,* and *Treponema socranskii*. Some of the bacterial species that are routinely isolated from endodontic abscesses are *F. nucleatum, P. gingivalis, P. endodontalis,* and *P. intermedia.*

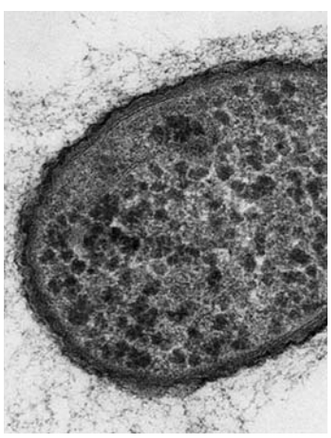


3.9 Electron microscopy of bacteria

Left: In cases of acute AP, the large numbers of bacteria exiting the pulp and entering the periapical tissues overwhelm the capacity of the host's defense system (leukocytes). High levels of hydrolytic lysosomal enzymes are released into the tissues (degranulation), which leads to tissue destruction, swelling, and pain.

Right: A thin section with *T. denticola* cells, which are often observed in cases of both acute and chronic endodontic infection. The histologic section shows the intracellular flagella that are typical of oral treponemal organisms.





3.10 Bacterial capsule

Left: Electron photomicrograph of the thick capsule of *P. gingivalis*; the capsule makes the cell more resistant to host defense systems.

Right: Electron photomicroscopic depiction of the thick, yet loose, capsule of *P. denticola*, a Gram-negative, black-staining, anaerobic, rod-shaped species.

Posttreatment Endodontic Infection

Posttreatment endodontic disease is often a result of inadequate asepsis during and after treatment. The composition of the microbiota in a case of posttreatment endodontic infection is different from that of the primary infection. Ecologic changes resulting from the treatment have a major role in determining the species that can survive in the root canal. Facultative species are more resistant than anaerobic bacteria, and Gram-positive bacteria are better survivors than Gram-negative bacteria.

In teeth with endodontically filled roots, the space available for the microbes is limited, and the numbers of bacteria retrieved from root-filled teeth with persisting infection are lower than those in teeth with primary AP (Molander et al., 1998; Peciuliene et al., 2001; Siqueira et al., 2002).

E. faecalis is the dominant isolate in samples from posttreatment endodontic lesions (Molander et al., 1998; Hancock et al., 2001; Peciuliene et al., 2001). Facultative Gram-negative enteric rods have also been detected in posttreatment apical periodontitis. Furthermore, streptococci, coagulase-negative staphylococci, *Lactobacillus* sp., and *Candida* sp. are among the species that are clearly more frequently observed in samples from root-filled teeth than in teeth with untreated necrotic pulps (Siren et al., 1997; Waltimo et al., 1997; Chavez de Paz et al., 2003, 2005). Gram-negative facultative rods isolated from these infections include many enteric species such as *Enterobacter cloacae, Enterobacter agglomerans, Enterobacter sakazakii,* and *Klebsiella oxytoga.*

Acinetobacter sp. and *Pseudomonas aeruginosa*, and *Proteus* sp. have also been isolated. *E. faecalis* and enteric rods can occur singly, however, usually enteric bacteria are isolated together with other bacteria. Posttreatment endodontic infection is usually symptom-free or is accompanied by only mild symptoms. *E. faecalis* has been shown to be more associated with symptom-free than with acute cases.

3.11 Postendodontic infection

Left: Radiograph of a maxillary first molar treated 3 years previously for pulpitis. Subsequently, radiolucent lesions developed around the mesiobuccal and distobuccal root apices. A possible etiology is the poor seal around the composite restoration.

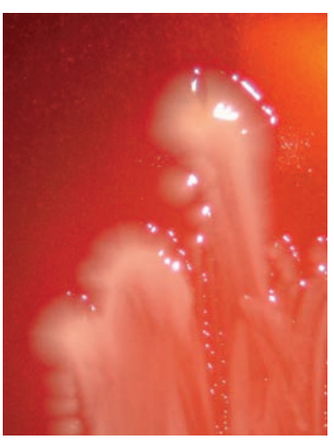
Right: Occasionally, a vertical root fracture may be the cause of a persisting infection. In addition to the post itself, numerous other factors probably contributed to the root fracture. Vertical root fractures cannot be treated, and the tooth had to be extracted.

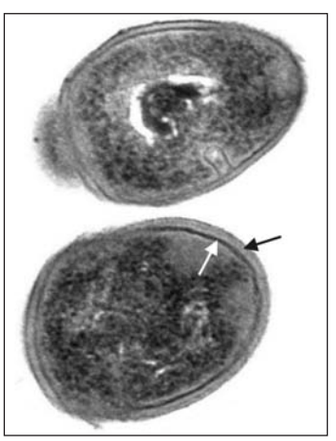
3.12 Microbiologic findings

Left: Inadequate cleansing and filling of the apical root canal: Although the canal was filled with a gutta-percha point and a layer of sealant, there were several areas still containing necrotic tissue and microorganisms.

Middle: Colonies of *E. faecalis* on a blood agar plate following 24 hours of aerobic culture at 37 °C.

Right: Scanning electron photomicrograph of two cells of *E. faecalis* showing the typical Gram-positive cell wall (white arrow: cytoplasmic membrane; black arrow: peptidoglycan layer).





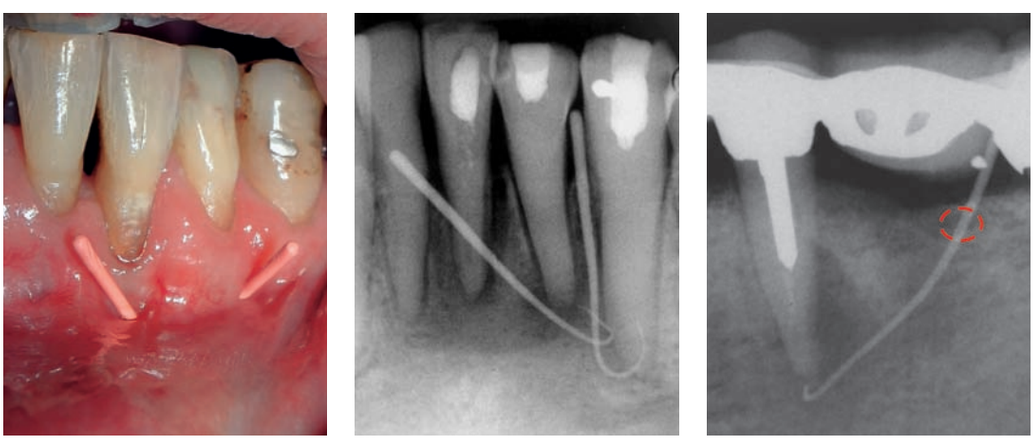
Spreading of Endodontic Infections

A fistula is a common way of spreading an endodontic infection, and it usually opens intraorally in the alveolar mucosa, close to the apex of the affected tooth. Cellulitis is an acute, diffuse, spreading, edematous, and suppurative inflammation of the connective tissues which may involve the deep subcutaneous tissues and even muscle. Cellulitis may also be associated with abscess formation. In cases of severe infections, hospitalization must be considered. An abscess per se is anatomically more defined than cellulitis, (i.e., an abscess is a *localized* infection with pus formation.)

Spreading of the infection is dependent on local anatomy. The anatomic relationship of the apex of the infected tooth and the facial muscles is of particular importance in determining the *direction* of spread. The key muscles affecting the pattern of spread include the levator anguli oris (canine region), buccinator (cheek region), masseter, pterygoideus, and temporal muscle (region of the masticatory musculature), as well as the mentalis (submental region). Odontogenic infection may also spread into the lateral pharyngeal and retropharyngeal spaces or even into the mediastinum. Rarely, deep fascial infections create a potential risk for patients with endodontic infections. It is important not to misdiagnose these as localized endodontic abscesses. Although rare, maxillary infection in the canine space may give rise to cavernous sinus thrombosis.

Bacteremia of short duration is a common consequence of many dental procedures, including endodontic treatment. Overinstrumentation may lead to direct seeding of bacteria into the bloodstream. Bacteria may also advance through the tissues into the lymphatic system. Further progress beyond the lymph nodes may result in bacteremia or even septicemia.

Instrumentation of an infected root canal is a common cause of transient bacteremia (Heimdahl et al., 1990). The number of bacteria recovered per milliliter of blood is lower in endodontic bacteremias than in bacteremias after tooth extraction or periodontal scaling (Heimdahl et al., 1990).

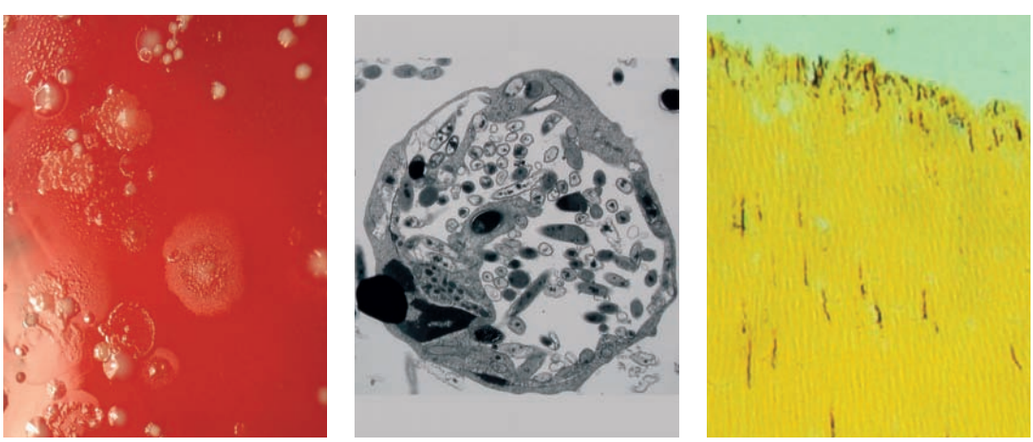


3.13 Fistulous tracts

Left: Clinically apparent orifices of two fistulous tracts from acute AP lesions. An acute infection always spreads along the path of least resistance, resulting frequently in buccal or lingual fistulous tracts.

Middle: Radiographic depiction of the fistulous tracts.

Right: Acute apical periodontitis with a fistulous tract from a mandibular second premolar. The wide tract opening (red outline) is distal to the posterior edge of the periapical infection.



3.14 Cultural and microscopic examination

Left: Mobile anaerobic bacteria that were isolated from an endodontic infection and cultured on a blood agar plate under anaerobic conditions.

Middle: A granulocyte that has engulfed too many bacteria and died. This is a typical picture of a spreading infection, often with pus formation.

Right: The infection spreads from the primary root canal into lateral canals via the dentinal tubules. The dark dots and streaks in this photomicrograph represent Gram-positive microorganisms within the dentinal tubules.

Periapical Actinomycosis and Other Extraradicular Infections

In periapical actinomycosis, bacteria, *Actinomyces* spp. in particular, are permanently present in the periapical area (Borssen and Sundqvist, 1981; Nair and Schroeder, 1984; Happonen, 1986; O'Grady and Reade, 1988; Figdor et al., 1992). The pathogenesis of periapical actinomycosis is only partially understood.

It is possible that actinomycosis may develop after the initiation of the endodontic treatment, when the intracanal biofilm has been pushed out of the canal by instrumentation. Although *Actinomyces israelii* is susceptible to phagocytosis, the dense colony structure of actinomycosis protects individual bacterial cells from being effectively phagocytosed (Figdor et al., 1992).

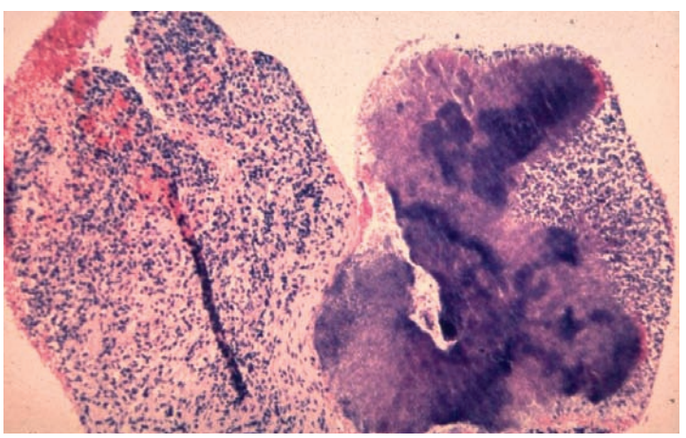
Some studies have indicated that extraradicular infection may be caused by bacteria other than *Actinomyces* (Haapasalo et al., 1987; Tronstad et al., 1987; Wayman et al., 1992; Brauner and Conrads, 1995). Studies employing cultural and molecular methods have indicated the presence of several different species in extraradicular infections (Gatti et al., 2000; Sunde et al., 2000a, b). However, the frequency of extraradicular infections has not been studied. Evidence is accumulating that *T. forsythensis* is sometimes present in extraradicular infections. However, despite early reports to the contrary, recent publications do not support the presence of *Aggregatibacter (Actinobacillus) actinomycetemcomitans* in these infections.

Studies by Waltimo et al. (2003) on yeasts and Chan et al. (2004) on bacteria both showed the importance of positive controls and sequencing of the polymerase chain reaction (PCR) products to avoid false-positive results in the analysis of microbial presence in periapical lesions. Using fluorescent in situ hybridization, Sunde et al. (2003) localized *P. gingivalis, T. forsythensis,* and *P. intermedia* in 9% of periapical lesions.

3.15 Actinomycosis I

Histologic section through a periapical actinomycosis lesion. The peripheral area shows heavy infiltration of inflammatory cells surrounding the homogeneous, darkly stained actinomycotic region. Note the large, densely packed colony of *Actinomyces* sp. (Courtesy of Dr. R. P. Happonen.)

Right: An endodontic working length radiograph in a middle-aged patient with periapical *Actinomycosis* infection related to a mandibular canine. Note also the questionable condition of the premolar.

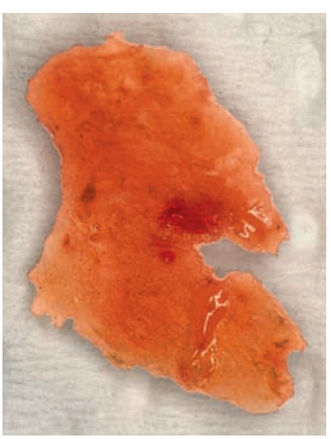


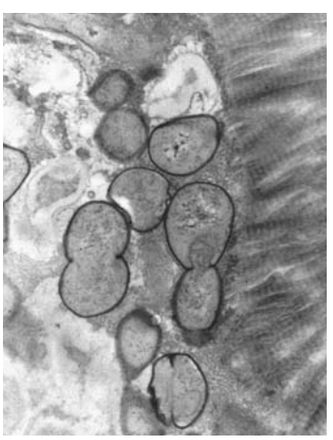
3.16 Actinomycosis II

Left: A bone sequestrum that penetrated through the buccal mucosa of a patient with periapical actinomycosis.

Middle: Histologic section of the specimen. Note the lamellar bone (*) and three actinomycotic colonies in the middle, with loose infiltration of inflammatory cells nearby.

Right: Thin section of an actinomycosis extraradicular lesion. In addition to the bone collagen fibers, there are numerous bacteria with typical Gram-positive bacterial cell wall structure.



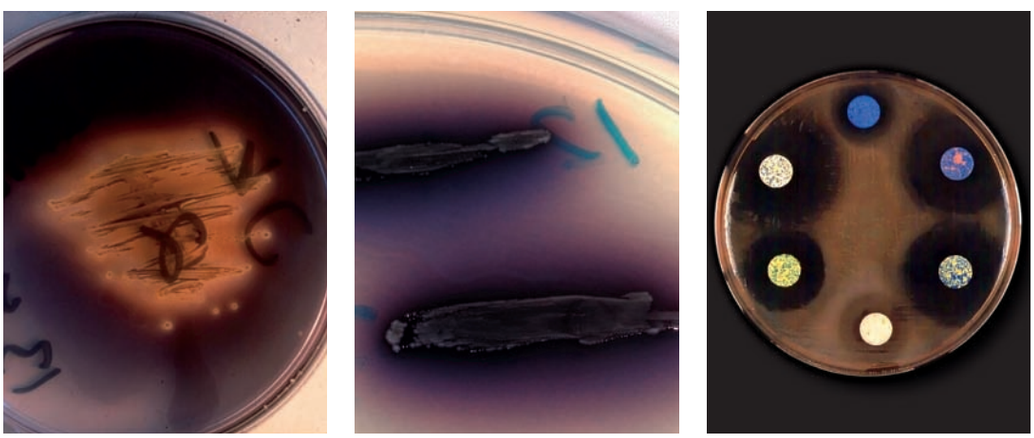


Techniques for Studying Endodontic Microbiota

Endodontic microbiota can be analyzed by a variety of methods. These include culture, a variety of staining methods using light microscopy, electron microscopy, immunologic techniques, and an increasing number of molecular methods characterizing the microbial DNA or RNA (Haapasalo et al., 1986a; Happonen, 1986; Siqueira et al., 2001; Fouad et al., 2002).

The choice of technique used is dependent on availability of resources and the goal of the investigation. When antibiotic susceptibility of the causative organisms is needed, culture methods have priority. For etiologic and epidemiologic studies, methods using DNA amplified by PCR and other molecular techniques are used. These include PCR, real-time PCR, nested PCR, quantitative PCR (Q-PCR), reverse transcriptase PCR (RT-PCR), species specific primers, 16S rRNA sequencing, DNA sequencing, pulse field gel electrophoresis (PFGE), denaturing gradient gel electrophoresis (DGGE), restriction fragment length polymorphism (RFLP) (fluorescent) amplified fragment-length polymorphism ([F] AFLP), fluorescent *in situ* hybridization (FISH), and DNA microarrays (Baumgartner, 2004; Siqueira and Rocas, 2005). Electron microscopy is suitable for the study of bacterial cell wall structures, e.g., virulence factors such as the capsule, and the structure and location of bacterial biofilms.

Microbiologic methods, DNA/RNA techniques in particular, have greatly improved during the past few years. However, none of these methods is completely error-free. The problem of false-negative and false-positive results remains a challenge, and quantitative results are not possible with many of these techniques.

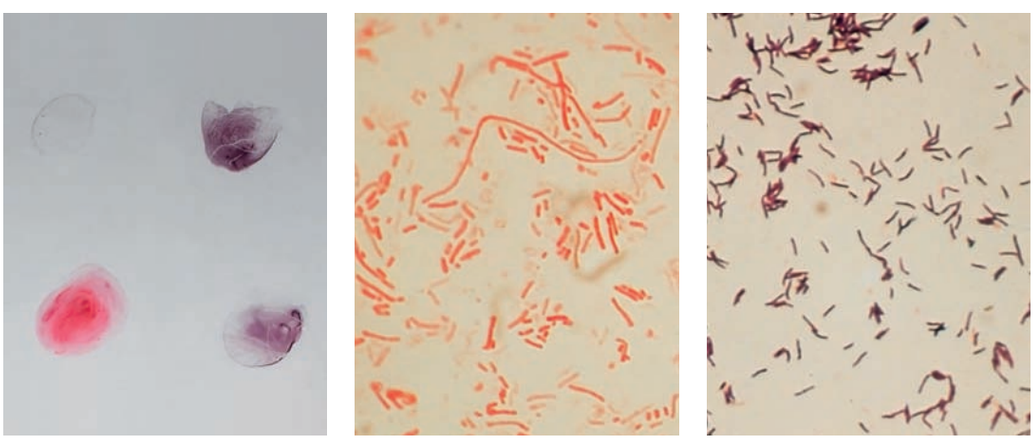


3.17 Test procedures

Left: Starch hydrolysis test to indicate the presence of anaerobic bacteria. Iodine solution stains the starches in the medium dark blue if they have not been hydrolyzed by bacteria.

Middle: Bile Esculin agar used to differentiate enterococci from other bacteria. The dark color indicates positive growth, as well as the capability for Esculin hydrolysis.

Right: Sensitivity test for facultative aerobic and anaerobic bacteria using a special medium that does not interfere with the effects of the antibiotic medication.



3.18 Gram staining

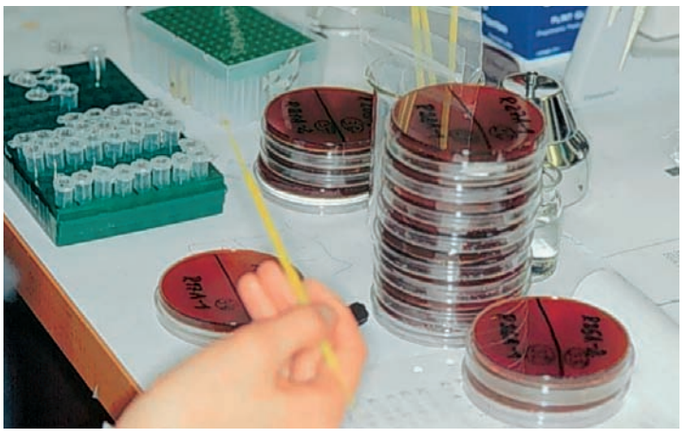
Left: Gram staining of an endodontic sample. Gram-negative bacteria assume a red color, while Gram-positive bacteria and yeasts stain blue.

Middle: The pleomorphic, Gram-negative anaerobic rod *Prevotella* sp., isolated from a case of acute apical periodontitis. The cellular morphology ranges from coccoid to very long rodlike shapes.

Right: Microaerophilic/facultative anaerobic, Gram-positive rod-shaped bacteria, genus *Actinomyces*. The cells appear straight or slightly curved.

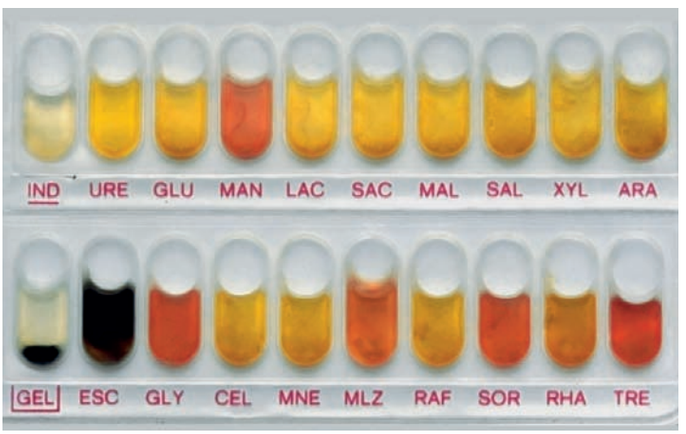
3.19 Preparation of a microbiologic sample

In a microbiologic laboratory, the specimens are prepared upon various selective and nonselective culture media to culture and identify the various bacterial species.



3.20 Fermentation set

Fermentation set for the identification of anaerobic bacteria. The color indicators in the test ampoules change to a yellow color following production of acids by the bacteria from the various carbohydrates.



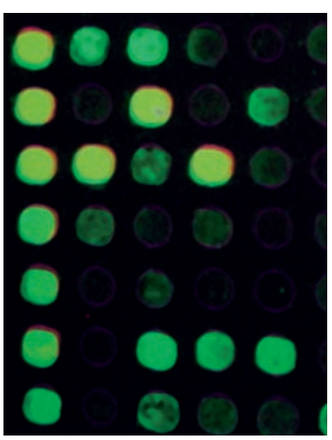
3.21 Enzyme test set

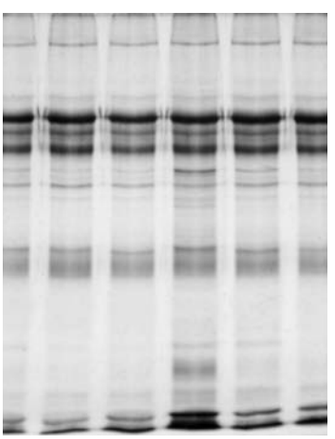
Enzyme test set for detection of the presence and the production of glucosidase and aminopeptidase enzymes, which are identifiers for numerous anaerobic and facultative anaerobic bacteria. The moment an enzyme metabolizes a certain substrate, previously invisible molecules become colored and are released into the medium revealing enzyme activity.

3.22 Modern test techniques

Left: DNA microarrays permit the testing and identification of numerous genes or DNA sequences using an automated reading system. Specific probes are “injected” onto the walls of the chips, and subsequently used to identify the substances within the sample. The strength of the signal is characterized in various colors within the fluorescent array.

Right: Silver-colored polyacrylamide gel following gel electrophoresis. This test is performed to compare the various strains of *Candida albicans* in order to ascertain differences between individual isolates.





4 Endodontic Diagnosis

The goal of endodontic diagnostic procedures is to determine the condition of the pulp and the periradicular tissue. Diagnosis is difficult because it is impossible to directly inspect the pulp and the clinician has to rely on indirect methods of examination.

Patients who present with pain in the facial region often have pulpal or periradicular disease. Within a very short period, the dentist must arrive at the proper diagnosis and devise a targeted clinical and therapeutic regimen which relieves the patient's pain and assures long-term maintenance of the affected tooth. In terms of the appointment structure within the dental practice, this presents an important challenge for the dentist. However, no diagnostic method has *perfect* sensitivity and specificity. Knowledge gleaned from the patient's chief complaint, medical/dental history, appropriate clinical tests, and differential diagnosis, will in most cases lead to an accurate diagnosis and subsequent successful treatment.

The absence of clinical symptoms does not necessarily mean that the pulp is completely healthy. In the case of infection with bacteria with minimal virulence, or in the case of strong immunologic resistance within the pulpal tissues, a transient acute inflammation can become chronic and be detected by chance, for example due to crown discoloration or lack of pain or painlessness during the placement of a restoration. Conversely the acute phase may develop within a chronic process. Infection may also be primarily acute. Pain as a diagnostic criterion of endodontic disease has relatively low sensitivity. According to Langeland et al. (1994), there is *no correlation* between clinical signs and symptoms and the histopathologic status of the pulp, although in one study 80% of the patients who presented with dental pain had histological evidence of an irreversible alteration within the pulp (Dummer, 1980). There is also no direct correlation between the severity of pain and the progression of the inflammatory process, (i.e., between the specific types of bacteria and the clinical symptoms) (Dummer, 1980).

To quickly establish an appropriate working diagnosis, it is wise to follow a systematic procedure (e.g., from the outside to the inside). All clinical investigations regarding pain intensity should always be interpreted in comparison with the adjacent and/or contralateral teeth. This helps to establish clear comparisons with regard to both the objective and subjective reactions of each individual patient. In the case of multirooted teeth, the diagnosis is rendered much more difficult due to the different histopathologic conditions within the pulp of the individual root canals.

Tenderness to percussion indicates an extension of pulpal inflammation into the periapical tissue (e.g., periodontal ligament). Pulpitic and/or periapical discomfort may radiate to other areas of the jaw and face, but almost never crosses the facial midline (Seltzer et al., 1963). Pain originating from the mandibular teeth is often referred to the periauricular area, and pain originating from maxillary teeth may be referred up to the temple.

If the patient reports bilateral pain, one must consider systemic disease rather than pain of odontogenic origin. In such cases, although a patient may believe that the teeth are the origin of their discomfort, the pain is actually originating elsewhere. Natkin et al. (1975) observed cardiac etiologies in 18% of patients presenting with supposed tooth pain. The possible pulpal and periapical diagnoses are listed below (the transition between the individual pulpal states is sometimes vague):

- clinically healthy pulp;
- reversible pulpitis;
- irreversible pulpitis;
- necrosis;
- apical periodontitis (acute or chronic).

Medical History and Clinical Examination

The information gleaned from the patient's medical history should clarify whether the patient has any systemic medical disease or whether any medications are being taken that could influence the treatment and prognosis of endodontic therapy. The best method for taking a medical history is to use a standardized questionnaire.

In general, there are no contraindications to endodontic treatment; however, each patient's physical and psychologic condition should be considered. If the dentist is in any way uncertain, the patient's general physician or a medical specialist should be consulted before the initiation of endodontic treatment.

As a basic principle, the medical history should be reviewed and updated before each endodontic appointment. If the medical history reveals pre-existing conditions such as endocarditis, heart valve replacement, or rheumatic fever, antibiotic prophylaxis is indicated before root canal therapy. In the case of other conditions such as glaucoma, asthma, or pregnancy, epinephrine-containing anesthetic solutions should not be used. In patients with diabetes, human immunodeficiency virus (HIV) infection, or following radiation therapy, one must remember that the course of healing will be longer. It is also critically important to note the presence of any allergies (e.g., latex, penicillin).

4.1 Patient information

Information concerning root canal treatment

Dear Patient,

Your treatment plan will include root canal therapy. This document contains important information about root canal treatment; if you have any more questions or concerns you can obtain additional details and information from your dentist.
Root canal treatment becomes necessary if the nerve within the affected tooth (pulp) becomes inflamed or is already dying. This condition often causes toothache, but it may also remain unnoticed and be detected by chance, for example through use of a pulp tester or on a radiograph.

Root canal treatment is usually the "last chance" to maintain the diseased tooth. No dentist can offer a guarantee of success.

The affected tooth will first be isolated from the oral cavity by means of a rubber dam (latex rubber). This protects you from possibly swallowing dental instruments or rinsing solutions, and additionally guarantees a sterile and compact field of operation for the dentist.
The inflamed nerve will be removed from the tooth, the root canal will be cleaned using small instruments called files and disinfected. It will then be filled with a biocompatible substance (gutta-percha) in combination with a sealer cement. If the nerve is not yet completely necrotic, you will first receive a local anesthesia. During the root canal treatment procedure, some radiographs will be required. Depending upon the number of root canals in the tooth (up to four), and how easy it is to clean and shape these canals, several time-consuming appointments will be necessary. If unexpected problems occur, the time of treatment may be extended, or it may be decided that restoration of the tooth is impossible and that it must be extracted (taken out).

As with every dental procedure, there may be some complications while doing a root canal treatment, even though the utmost care has been taken. These include:
– swelling or discomfort of the affected tooth—this usually occurs within the treatment period, between the appointments, but it may occur some later time following completion of the root canal treatment;
– injury to the root canals by instruments or inserted posts;
– Instrument fracture;
– tooth fracture;
– unusual and unanticipated damage to the nerves within the lower jaw
– perforation of the maxillary sinuses, because the roots of some teeth are very close to them;
– overfilling of the root canal.

Alternatives to root canal therapy include dental-surgical procedures in which the apex of the diseased root tip is removed (apicectomy). In the posterior teeth only the compromised root may be completely removed. If all else fails, the only possible treatment will be removal of the tooth.
If you decide against the recommended root canal treatment, because you may be pain-free, without any clinical signs and symptoms and your condition was only detected by chance during routine radiographic examination, you should understand that the inflammation of the tooth pulp may progress towards the maxillary sinuses or into and along the nerves of the lower jaw; this can lead to pain, swelling and abscess formation with suppuration.
Following the initial root canal appointment, and following the abating of the local anesthesia (approximately 2 hours) some mild to moderate discomfort may occur in the affected tooth. This discomfort usually subsides in intensity; however, it may persist for 2–3 days following the treatment. You may need to take over-the-counter pain medication, e.g., ibuprofen.
In the case of more intense pain or increasing pain, we ask that you telephone the office immediately for an additional appointment. We request that you refrain from driving for at least one hour after the end of the procedure as the anesthetic will still be having an effect.
Following root canal treatment, the crown of the affected tooth may become esthetically compromised, i.e., "discolored."
With successful root canal treatment of the tooth, its long-term survival (especially in the posterior segment), depending on the loss of tooth structure, should be enhanced by the subsequent placement of a partial crown or a full crown, sometimes involving the use of a pin or a post within the filled root canal. This is a firm recommendation.
By signing this document, you confirm that you have been informed about the necessity for the root canal procedure, the procedure itself, the possible complications, and alternatives to root canal treatment, and that you agree to undergo this therapy.
I have been informed about the necessity, possible complications and alternatives to root canal treatment. I have no additional questions. As attested by my signature, I confirm my willingness to undergo the procedure.

_____ _____
Patient Signature Date

The patient's dental history must include questions concerning previous dental visits, recently placed restorations or pulp capping procedures, and any previous complications associated with dental treatment.

If a patient presents as an emergency, the primary complaint should first be recorded briefly in the patient's own words. Details to be documented include pain localization, duration, and quality/quantity, as well as any stimuli that trigger, increase, or relieve the pain. After questioning the patient, a comprehensive examination of the entire intraoral environment should be carried out. If a tooth is suspected of requiring endodontic treatment it should be assessed in terms of restorability and strategic importance.

The decision about endodontic treatment should be made only after a comprehensive assessment of the clinical findings, the primary complaint, medical/dental history, and the differential diagnosis, which is the only relatively reliable way to reach an accurate diagnosis. This allows rapid planning of targeted therapy to reduce the patient's discomfort.

It is obligatory to inform the patient not only about the prognosis and procedures involved in endodontic therapy, including the necessity for numerous radiographs, possible complications, but also about the financial burden of the endodontic therapy itself and subsequent costs of necessary prosthetic treatments after successful root canal therapy.

Extra- and Intraoral Examination

The extraoral examination begins when the clinician greets the patient. During this time any atypical external facial features should be noted including facial asymmetry (e.g., swelling, skin color, the appearance of fistulae and localized redness, etc).

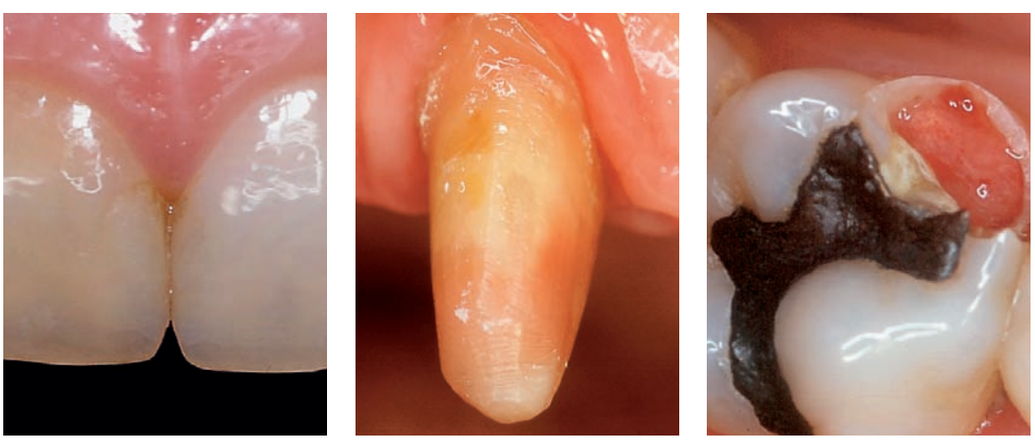
Extraoral bimanual palpation, including a comparison of the submandibular and cervical lymph nodes on both sides may provide clues about any spread of infection or the presence of tumorous diseases. It is essential to clarify whether a localized or generalized condition represents the etiology of any abnormality noted. The masticatory muscles should be palpated bimanually. The mouth opening should also be checked: It should be at least three fingers' wide for root canal treatment to be carried out.

The intraoral examination includes an assessment of the general dental status combined with careful examination of the hard and soft tissues for swellings, sinus tracts, crown discoloration, or tooth mobility. The condition of the hard and soft tissues (tongue, lips, cheeks, palate, and neck) as well as the status of the dentition, the periodontium, and the oral hygiene, and number and quality of dental restorations should be recorded.

4.2 Extraoral examination

Left: Submandibular abscess extending posteriorly from the mandibular left second molar.

Right: Extraoral cutaneous fistula caused by odontogenic infection.

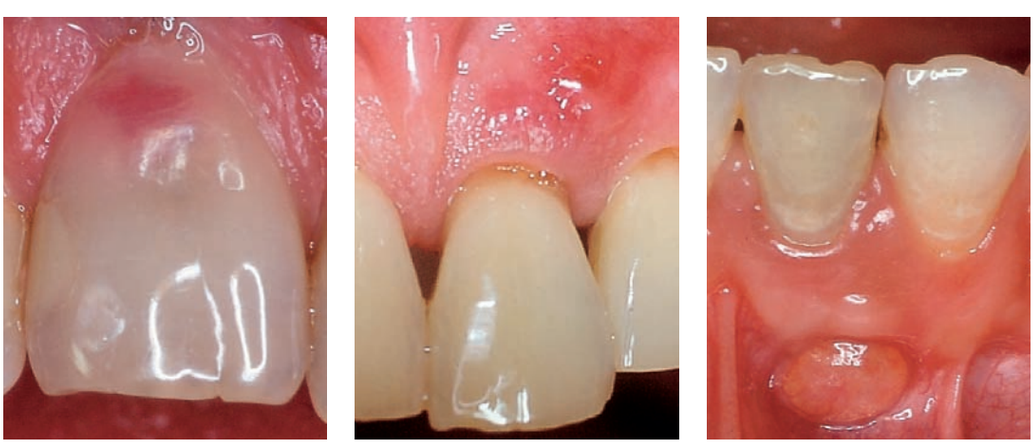


4.3 Intraoral examination

Left: Discoloration of the crown of the maxillary first incisor resulting from accumulation of hemosiderin in the dentinal tubules.

Middle: Intrapulpal hemorrhage following crown preparation.

Right: Hyperplastic pulpitis: "pulp polyp." Proliferative nature of pulp tissue after chronic irritation (e.g., caries, most often observed in young teeth).



4.4 Intraoral examination

Left: Pink spot: Typical appearance of internal resorption by odontoclastic cells.

Middle: Typical appearance of an intraoral sinus tract.

Right: Atypical clinical picture of an intraoral sinus tract.

Diagnostic Tests

The following examination procedures should be used routinely and in full for each patient: palpation and percussion, determination of tooth mobility, pulp tests, and periodontal and radiographic examinations. As mentioned in the previous section, while carrying out clinical tests, one must always include comparisons with adjacent and/or contralateral teeth. Additional tests include occlusal analysis, transillumination, selective anesthesia, special bite tests, and/or test cavities if there is any doubt about the condition of the pulp.

Tenderness to palpation in the region of the apices of the teeth (e.g., fluctuation or induration of the tissues and/or a positive percussion test), usually carried out by tapping the teeth with the handle of a dental instrument, are classis signs of advanced stages of inflammation involving the periapical structures. The mobility of a tooth may be increased following occlusal trauma, crown or root fracture, or as a result of periapical inflammatory processes.

Periodontal probing should be carried out in relation to the entire dentition to permit differential diagnosis between endodontic and/or periodontal etiologies.

An occlusal analysis can provide information about premature contacts in restorations or improper tooth loading, either of which may clinically simulate pulpitis. Removal of such premature contacts may lead to disappearance of the pulpitis-like symptoms in a short period of time.

A selective bite test using a bite stick ("tooth slooth") may help in the diagnosis of complete or incomplete fractures: pain typically occurs on release of bite pressure.

Transillumination can assist in the diagnosis of interproximal caries, and may also provide information concerning cracks in the enamel and/or dentin or complete fractures. The penetration of light is considerably reduced behind the fracture line.

In difficult cases, it may be necessary to use selective anesthesia, in which the suspect tooth is anesthetized, for example with an intraligamentary injection.

If the clinician still remains uncertain about the condition of the pulp, it may be necessary to remove an existing restoration or perform a test cavity without anaesthetizing the tooth. This procedure demands a tentative diagnosis, and must be considered the last diagnostic method of choice.

After carrying out all the investigations described here, in combination with the primary complaint, the medical and dental history, and the differential diagnosis the dentist should be able to achieve a relatively precise diagnosis, and therefore also plan an individualized treatment regimen.

4.5 Clinical findings

Left: Intraoral soft-tissue swelling originating from infection of the maxillary lateral incisor.

Middle: Intraoperative examination of the floor of a cavity; the pulp was exposed by the caries process.

Right: Pulpal diagnoses. Overview of the most common signs and symptoms (primary symptoms) of pulpal inflammation.

Reversible pulpitis

- Increased sensitivity to cold that subsides as soon as the stimuli is removed
- Positive response (to thermal or electric) pulp test

Irreversible pulpitis

- Prolonged sensitivity to heat or cold
- Positive response to pulp test

Necrosis

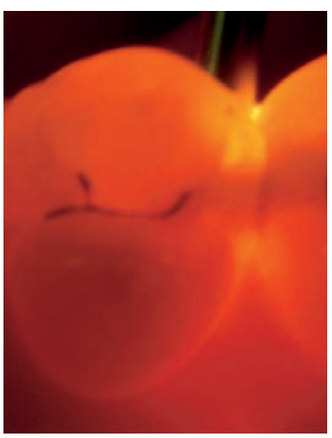
- Usually no response to thermal or electric pulp test

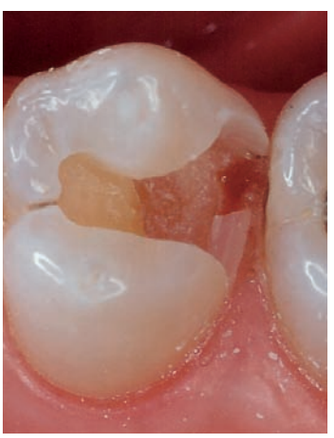
4.6 Diagnosis of caries

Left: Diagnosis of distal interproximal caries in the maxillary left first premolar, by means of transillumination.

Middle: Exposure of the pulp after caries removal in the maxillary left first premolar following cavity preparation.

Right: Periapical diagnoses. Overview of the most common signs and symptoms (primary symptoms) of periapical inflammation.





Acute apical periodontitis with/ without abscess

- Pain during chewing and/or with percussion
- Tenderness to palpation in the nearby gums, swelling

Chronic apical periodontitis

- Usually asymptomatic and an incidental radiographic finding
- Negative response to pulp and percussion test

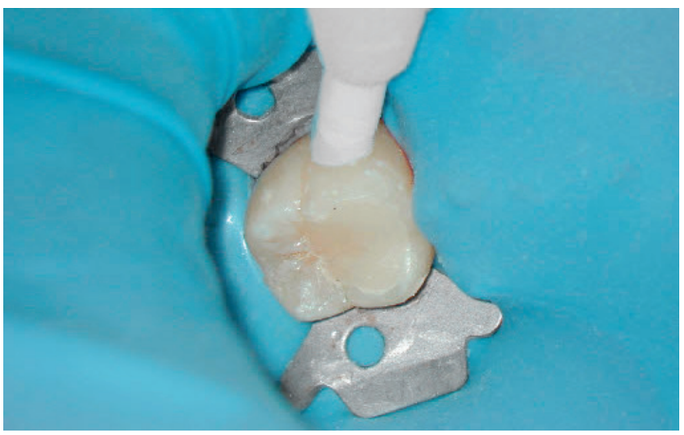
Pulp Tests

The pulpal sensibility test is an indirect method of determining the condition of the pulp and provides information about the vitality of the sensory nerve fibers. The inflamed pulp reacts in a hypersensitive way, whereas necrotic pulp does not respond. In multirooted teeth the test is more difficult to carry out due to the possible differing histologic conditions within the pulps of the individual root canals. In addition, pulp tests do not allow differentiation between various stages of pulpal disease.

Any pulp test should be carried out on a dry tooth surface at the cervical region of the tooth, and a comparison made with the adjacent or contralateral tooth. The tooth should be touched only briefly (do not wait until the patient experiences pain!).

In patients presenting with complete ceramic restorations the teeth may not react to pulp tests because ceramic isolates the tooth; in patients with proximal metallic restorations, these should be separated using rubber dam or plastic strips because of conduction of the stimulus to the adjacent teeth or to the attachment apparatus.

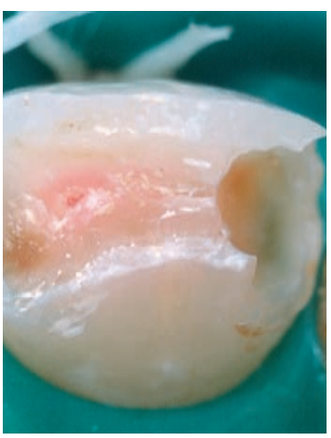
If the patient cannot precisely identify the offending tooth, the test should be carried out in reverse order or in combination with other clinical tests. A positive result may be achieved even when small apical radiolucent zones are visible on the radiograph. Pulp tests utilizing cold temperature (with a level of precision of 90%) are preferred over electrical (84%–88%) and heat tests (83%) (Petersson et al., 1999). The most convenient method involves using ice sticks made by freezing water or carbon dioxide snow. A complication in the form of enamel cracks using cold tests may occur at the earliest 2 minutes of application (Peters et al., 1994).



4.7 Pulp test

Left: A diagnostic ice stick made with frozen water in a needle cover can be used for cold testing.

Right: In this case, adjacent metallic restorations are evident, and the pulp test may be compromised due to carryover of the cooling effect. Separation of the teeth using a plastic or rubber strip may be helpful.



4.8 Delayed reaction to the pulp test

Left: The pulp tissue is often calcified in elderly patients. The pulp test in such cases is usually not helpful. It may be necessary to prepare a test cavity to investigate more fully the condition of the pulp. A radiographically visible calcification does not necessarily mean that the pulp is necrotic.

Right: Complicated crown fracture of a maxillary central incisor following traumatic injury. A pulp test immediately following such trauma may be negative.

The pulp test result will be influenced by the thickness of enamel and dentin, amount of reparative dentin, and presence of calcifications. Following dental trauma, the tooth in question may remain insensitive for several days or weeks. If the tooth has an immature apex or if the patient has taken analgesics, pulp vitality tests will be unreliable.

Failure to respond to such a test does not absolutely indicate a necrotic pulp. In such cases it is necessary to use additional diagnostic methods such as removal of a restoration in the suspect tooth or a test cavity without anesthesia in order to determine the condition of the pulp. In patients with a cardiac pacemaker, an electrical pulp test should be avoided.

Differential Diagnosis

Before determination of the final diagnosis and initiation of therapeutic measures, the clinician is wise to consider a comprehensive differential diagnosis which should include assessment of cervical defects, occlusal interferences, loose or fractured restorations, periodontal lesions, maxillary sinusitis, otitis media, or temporomandibular pain and/or myofascial pain dysfunction syndrome, all of which can induce pain that mimics endodontic problems.

Additional diagnostic tests will be necessary to identify true inflammation of the pulp.

Teeth with periodontal lesions often show an intact crown, and usually, a positive pulp test, and the periodontal probing depth is generally increased throughout the entire dentition. A negative pulp test on a previously compromised tooth with isolated vertical bone loss may lead to a diagnosis of endodontic pathology.

In maxillary sinusitis, usually the teeth adjacent to the sinus (premolars and molars) are painful and/or percussion sensitive, with a positive pulp test. Other conditions that need to be considered include facial pain and headache, which have a typical presentation, as does pain during movement of the head, especially while bending over and in combination with unilateral nasal blockage.

4.9 Pulpitis-like symptoms

Cervical erosion or wedge-shaped defects of the teeth may lead to sensitivity problems mimicking pulpitis.

Right: Premature occlusal contacts or occlusal discrepancies can lead to pulpitis-like symptoms. Such symptoms disappear quickly after removal of the premature contacts by selective grinding.

4.10 Interradicular and vertical bone loss

Left: Interradicular radiolucency that resulted from previous inadequate endodontic therapy in the presence of a deep isolated buccal pocket.

Middle: The lesion completely healed following successful endodontic retreatment.

Right: Vertical bone loss on the mandibular right canine that showed a positive pulp test, in association with generalized periodontal disease throughout the dentition.

4.11 Maxillary sinusitis

The patient presented with pulpitis-like symptoms in the right maxilla, and was unable to clearly localize the offending tooth. The maxillary right premolars and molars were caries-free (bitewing radiograph) but sensitive to percussion and also exhibited a clear response to the pulp test. The patient also complained of headache. Further questioning revealed unilateral nasal blockage, and pain while bending over.

Right: The radiograph shows an air-fluid level in the right maxillary sinus and confirms the tentative diagnosis.

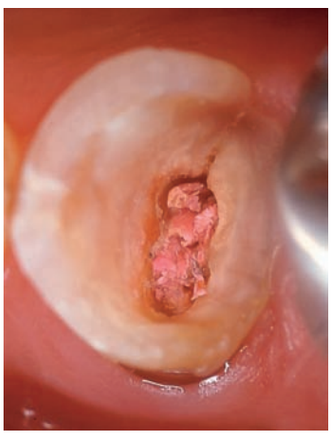
Fracture / Cracked Tooth Syndrome

Teeth exhibiting incomplete fractures ("cracked tooth syndrome") can respond with increasing sensitivity to cold, and pulpitic degeneration leading to necrosis of the pulp tissue is possible. Most typical is a short-term "release reaction" to pain following biting on a hard substance, which is due to stretching and rupture of the odontoblastic processes.

To determine the source of pain, reproduction of the patient's symptoms by applying selective biting pressure on a bite stick can clarify this diagnosis.

A correlation exists between the size of a dental restoration and the size of teeth exhibiting cracks. Prevalence is estimated to be 5.2 % – 15.2 %, with mandibular molars most often affected.

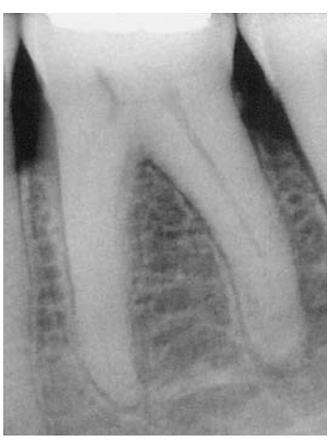
Teeth with vertical root fractures often have a long history of pain, combined with recurrence of symptoms, swelling, or a sinus tract. Many patients will have a narrow, locally isolated, deep pocket on the affected tooth, possibly with increased tooth mobility. Vertical root fractures are seldom seen on a radiograph, but sometimes a translucency is visualized along the periphery of the root, with typical V-shaped osseous resorption. Tamse et al. (1999) found that about 10.9% of extracted and endodontically treated teeth had vertical root fractures.



4.12 Vertical root fractures

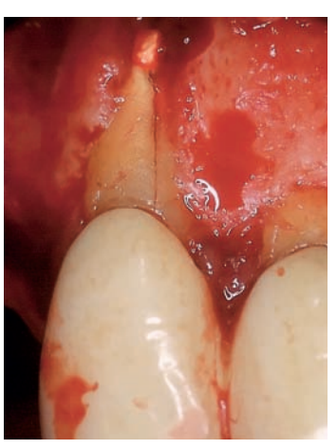
Left: Most commonly affected are the mesial root of the mandibular molars and the maxillary premolars. The cause of a vertical root fracture may be the root anatomy; in teeth with previous loss of tooth structure the cause may be over-preparation of the root canal or use of a post. The forces exerted during lateral compaction have also been implicated.

Right: Vertical root fractures are often not visible on the radiograph unless the plane of fracture happens to be at an appropriate angle to the x-ray beam.



4.13 Cracked tooth syndrome

The cracked tooth syndrome is the term used for incomplete fractures that may extend into the dentin. The prevalence varies between 5.2% and 15.2%, with mandibular molars being most often affected. The fracture line mostly courses from mesial to distal.



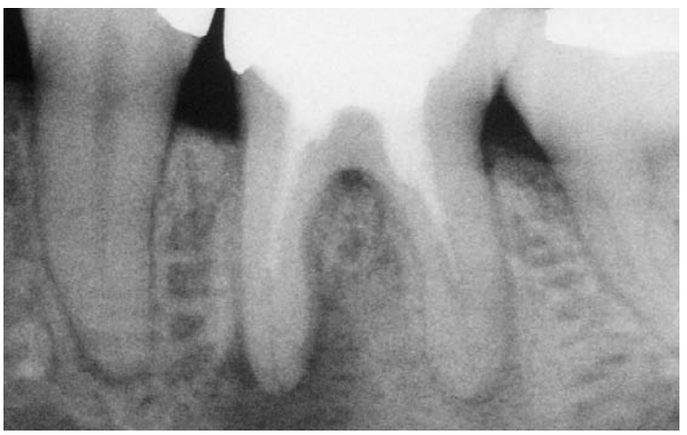
4.14 Vertical root fractures

It is often necessary to reflect a gingival flap to confirm a tentative diagnosis of vertical root fracture. This patient presented with a sinus tract in the region of the maxillary right canine, and reported a long history of pain in that region. Following radiography of the sinus tract traced with a gutta-percha cone it was possible to localize its source. Increase in periodontal probing depth on the tooth could not be confirmed. The vertical root fracture became apparent only after reflecting a mucoperiosteal flap.

Radiographic Examination

After completing the clinical investigations, the examination must be extended to include radiography, preferably using the right-angle technique. Such exposures will provide important clues about the anatomy of the tooth (extension of the pulp, as well as number, length, and any curvatures of the roots, pulp calcifications, resorption, periodontal condition, and previous dental treatment) and the surrounding structures; it must be noted, however, that diagnostic ability is limited by the two-dimensional image, which may cause diagnostic error. Therefore a definitive decision concerning therapy, based solely on the radiograph, is not acceptable. If the root canals are overlapping on the radiograph, it may be necessary to shift the tube for a mesially or distally angulated projection. If the patient reports what appears to be nonodontogenic dental pain, a panoramic radiograph should be taken and/or other diagnostic investigations also carried out.

Only if the apical lesion involves the *cortical bone*, will this be visible on the radiograph, with the actual defect being more extensive (Seltzer et al., 1963). According to Goldmann et al. (1974a, b), the interpretation of radiographs is associated with interobserver reliability of 47% and an intraobserver reproducibility of 72% after 6–8 months.



4.15 Initial radiograph

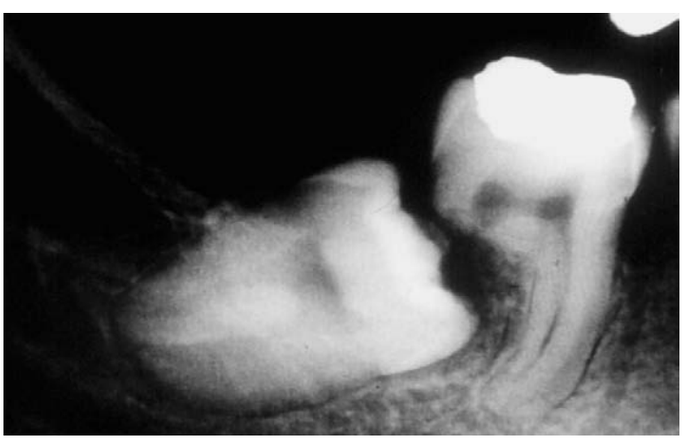
This radiograph was taken before attempting retreatment of a previous inadequate root canal filling. Note the apical lesion: the patient had tenderness to palpation and percussion.

4.16 Radiographic examination

Left: The radiograph revealed dens invaginatus. The young patient presented with a sinus tract in the region of the maxillary right lateral incisor with a positive pulp test of this tooth and the adjacent teeth.

Middle: Radiographic assessment of internal root resorption. This frequently follows dental trauma and is often detected incidentally.

Right: An obvious horizontal root fracture on a radiograph.



4.17 Initial radiographic findings

Radiograph of a mandibular right second molar before endodontic therapy. The retained and impacted wisdom tooth led to complete resorption of the distal root of the second molar.

5 Endodontic Radiology

Endodontic therapy without radiographic diagnosis is not possible. However, today, digital techniques are increasingly replacing traditional radiographic film technology, and also offering options for three-dimensional reconstructions of teeth and bone.

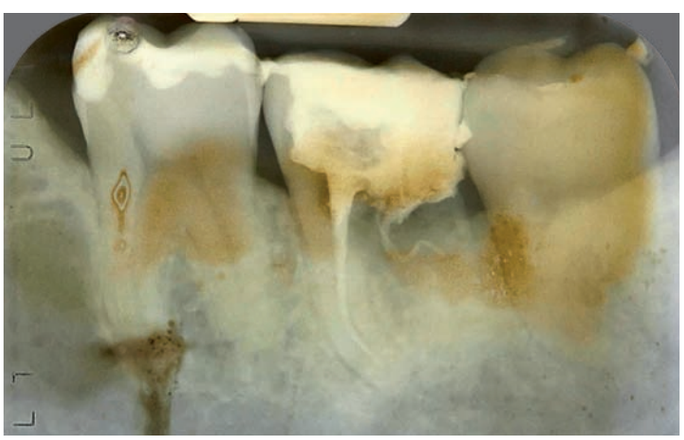
Radiographic Dose and Quality

Patient exposure to x-rays has been reduced considerably in recent years. In comparison with exposure from natural sources, the intraoral exposure has decreased to between 7.6 hours (Kodak Insight film, 6-cm exposure field) and 1.4 hours (with use of a semiconductor sensor). Whether or not this low exposure can be justified depends on the quality of the technical performance of the procedure. Only through the use of sensors or film holders, which provide the ability to take standardized radiographs, is it possible to accurately capture the anatomic relationships and compare sequential images. Errors in film processing are generally responsible for reduced image quality.

5.1 Poor projection

The patient moved the film packet against the alveolar process, so that the angle of projection was too steep. The teeth appear foreshortened, and the occlusal parts of the crowns are not visible. As a result the dental caries on tooth 26 was underestimated and tooth 27 was mistakenly treated.

Left: This example of a dissected specimen shows that if the palatal root of a maxillary molar appears considerably longer than the buccal roots, then the angle of projection of the x-ray beam was too steep in the vertical plane.



5.2 Poor development

Inadequate fixation had rendered this otherwise satisfactory film useless.

5.3 Using film holders

With the use of a film holder, the situation in the previous figure is better depicted on the radiograph, which now shows all relevant dental and other anatomic details.

Left: The less the palatal root is superimposed on the buccal roots, the better the right-angle projection to the long axis of the tooth (shown on dissected specimen).

Indications for Radiographs

The “European Guidelines on Radiation Protection in Dental Radiology” (and similar guidelines in the United States and other countries) provide for the first time an evidence-based guide to indications for radiographic examinations in dental practice. With regard to endodontics, the following regulations specifically apply: Diagnostic and final follow-up radiographs are an absolute necessity. A film for estimating the working length is necessary when electronic methods of estimation do not give a clear indication of the working length. In patients who are free of symptoms during the first year, a single follow-up radiograph 1 year after the treatment is adequate.

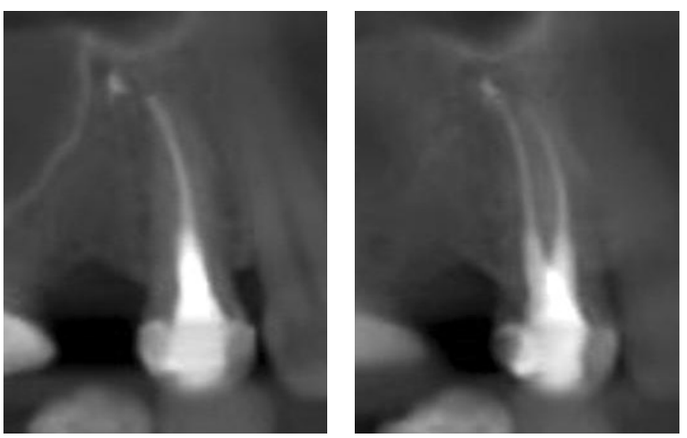
Digital or Analog?

Digital sensor technology and modern traditional radiographic films are equally suitable for endodontics. However, in endodontics, digital technology is preferable when it is readily available because the patient will be exposed to a lower total dose of radiation, increasing the likelihood of them consenting to additional images being taken.

Disadvantages with regard to image quality of digital systems in comparison with “wet film” techniques today no longer merit discussion. The relatively low resolution of sensor storage devices is of no consequence. The advantage of digital radiography is that the PC represents a much higher quality “developing” machine. The conventional radiographic film, because of its considerably reduced dynamics and the unpredictable influence of processing in the practice, much less frequently produces an optimum result. Over- or underexposed films, as well as over- or underdevelopment and poor fixation considerably reduce the relevant and clinically important information that can be gleaned from the image.

However, the increased versatility of digital systems is associated with some disadvantages when exposure times are too long. The digital image may still be useful, but the radiation exposure to the patient is nevertheless higher than necessary. To date, only one manufacturer offers automatic exposure control.

The “gold standard” for endodontology is the intraoral periapical radiograph. In individual cases, panoramic radiographs may offer a reasonable overview, but because of the lower resolution and the blurring of the image layer, they generally provide a poorer image quality. The third dimension is completely absent in both types of film, and as a result computed tomography (CT) and cone beam tomography are being considered.

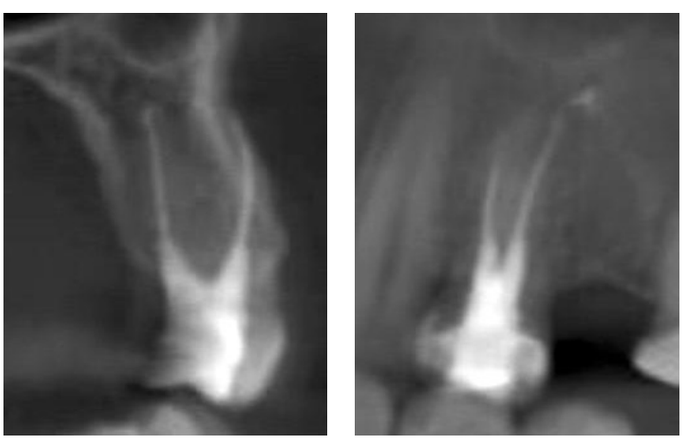


5.4 Cone beam CT image (Accuitomo)

Cone beam CT image (Accuitomo) image of a root canal filling in tooth 14.

Left: Buccal view.

Right: Distal eccentric projection.



5.5 Cone beam CT image (Accuitomo)

Left: Distal projection

Right: Palatal exposure, distal-eccentric (courtesy of Dr. Hubert Amschler).

Cone beam CT, with its large field of irradiation (NewTom, Aperio Inc., Sarasota, Florida, USA; MercuRay, Hitachi Medico Technology, Tokyo, Japan), is not indicated for use in endodontology because the doses involved are similar to those of dental spiral CT. Small-field cone beam CT (e.g., Accuitomo, J Morita Europe GmbH, Dietzenbach, Germany) may be used for special indications, for example root fractures, complex canal geometry or overfilling of canals.

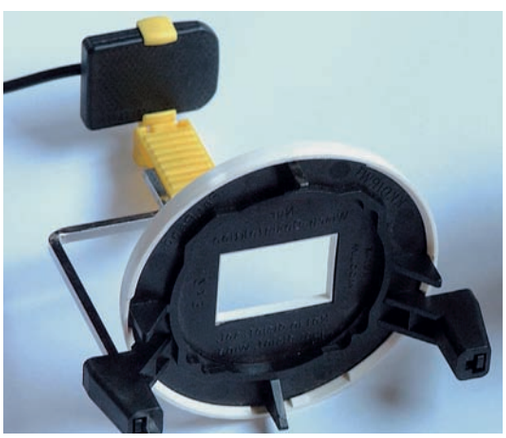
Depending on the size of the radiographic field (3 × 4 cm, 6 × 6 cm), both the radiation exposure and the resolution is similar to that of a digital panoramic radiograph (2.1 line pairs per millimeter only permit recognition of the tip of an endodontic file greater than ISO 25).

Film Holder Technique

The use of a film holder greatly improves the quality of radiographs taken. Standardized radiographs can be taken without cone shadowing. With the use of a collimator, radiation exposure is greatly decreased. At the same time, the reduced radiation scatter improves the film contrast. For over 30 years now, the Rinn XCP (Extension Cone Paralleling) system (Dentsply, Elgin, Illinois, USA) has proved its value in endodontology.

The film holder is inserted with the patient's mouth wide open; for mandibular radiographs the film or sensor is positioned between the tongue and the alveolar process and for maxillary radiographs it is positioned high in the middle of the palate. For the maxillary teeth the film/sensor is initially positioned parallel to the long axis of the tooth. If the film/sensor extends far beyond the incisal edge or occlusal surface of the tooth in question, the film should be tipped in the direction of the tooth crown. If the patient continues to bite reliably on the block, the film holder will not move from the predetermined position. If the patient cannot bite, cotton rolls can be placed between the film holder and the teeth. The collimator window is then oriented toward the tooth and the cone positioned vertically.

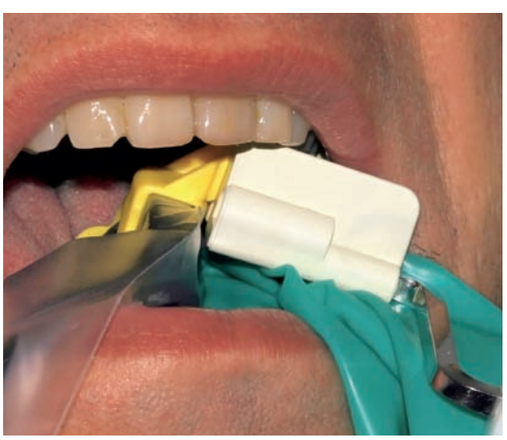
A specialized endodontic bite plate can be used for file and root canal length measurements, thus preventing contact with the file handle when the patient bites. Such plates do not permit jaw closure beyond what is necessary. If proper positioning in the distal segments of the oral cavity is not possible, the bisected angle technique without a film holder may have to be used. Sensors or appropriate radiographic films are then usually bent. However, owing to the artifacts caused by bending the film, the accuracy of file or canal length measurement becomes questionable.



5.6 Semiconductor sensor

Left: Semiconductor sensor with the XCP holder and collimator (RWT Window x-ray, Kentzler-Kaschner Dental, Ellwangen, Germany). The use of a collimator reduces radiation exposure while improving image contrast.

Right: Clinical view of the device being used on the right side of the lower jaw.



5.7 Endodontic bite plate

Left: The endodontic bite plate.

Right: Endodontic bite plate in situ.

6 Anatomy

The basic anatomic characteristics of the teeth have been known for many years. However, because of the wide variations in dimensions and clinical presentations, it is necessary to understand the dental anatomy for each patient and for each tooth before endodontic therapy is attempted, with particular consideration of the anatomy of the root canal(s)—the "endodontium"—and the surrounding tissues.

The first comprehensive and systematic description of root canal anatomy was published by Carabelli in 1844. His publication showed vertical and horizontal sections of teeth depicting in detail the root canal system and structure of the teeth. Since then, various methods have been developed to better depict and describe the root canal systems within the teeth. The current computed tomography (CT) techniques permit highly detailed three-dimensional (3D) images of root canal systems. These technical advances show promise of bringing fresh perspectives for endodontology in the coming years.

The earliest depictions of the highly variable, 3D nature of the dental pulp with lateral canals and arborization were published by Hess (1917; Zurich, Switzerland). He injected the root canals with a natural rubber and then removed the hard dental tissues using hydrochloric (muriatic) acid. These research preparations are still, even today, highly impressive and provide valuable descriptive material for all generations of students. Other research techniques (Adloff, 1913; Vertucci, 1974, 1984) rendered the enamel and dentin transparent, therefore allowing direct view of the internal tooth components and the fine tissue structure of the dental pulp.

It was in the 1950s that W. Meyer (Göttingen) helped provide the basis for a complete understanding of the apical third of the tooth root: serial sections 50 µm thick provided the basis for wax models of the distal 6 mm of a large number of teeth. Meyer demonstrated that the apical "delta" of the roots exhibits numerous lateral canals and arborization. The goal of endodontic techniques employing heat and chemical agents is to open and disinfect the "portals of exit" (POE) and then close those POEs using appropriate sealers. In the case of surgical root tip resection (apicectomy), it is desirable to remove the apical 3 mm of the tooth root and then to retrogradely instrument an additional 3 mm into the root canal system. Subsequently, the retrograde cavity is sealed with an appropriate material. On the whole, this procedure either removes or completely seals the apical 6 mm of the canal, thus eliminating the majority of lateral canals or isthmus structures (Weller et al., 1995).

Numerous studies have attempted to delineate the average number of roots and root canals, or to define ethnic differences. Such studies have provided some indications, but they remain only vague descriptions.

The radiographic depiction of the tooth and its root canal system remains the most important component of endodontic therapy. Many scientific investigations have dealt with this component; among these, the most extensive study involved 4183 extracted teeth with 7275 root canals (Pineda and Kuttler, 1972). It is somewhat unfortunate that the noninvasive, radiation-free technique of magnetic resonance imaging (MRI) has not yet contributed significantly to a better understanding of the microstructure of the endodontium. On the other hand, CT, micro-CT, spiral-CT or 3D CT techniques have provided unexpected advancements in the visual depiction of the fine anatomy and anatomic structure of the endodontium, a feat that was long considered impossible.

Computed Tomography—Clinical and 3D

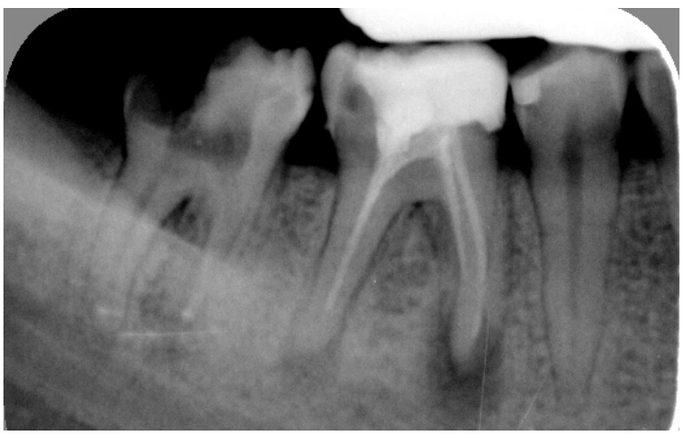
CT has been used in the field of dental implantology and preoperative planning for apicectomy for a long time (Velvart et al., 2001). The extreme precision and detailed resolution of micro-CT is clinically desirable, but due to technical limitations it is not yet a reality in routine endodontic practice.

The flat-panel, detector volume-CT provides very impressive images with high resolution, and in one in vitro study has demonstrated the capacity for 3D representation of vertical root fracture with a resolution of up to 140 µm (Hannig et al., 2005).

Clinical application of digital volume tomography (DVT) has already begun. With devices such as Accuitomo (J Morita) and Galileo (Siemens) it is possible to create images that use radiation dosages similar to those for panoramic radiographs but require less exposure time. Depending on the image area, a resolution of 125–300 µm is possible. In addition, instruments are now available with predetermined apertures (TACT = tuned aperture CT) that take numerous conventional 2D CT images and then mathematically compute a 3D image (Nair, 2003; Farman and Farman, 2005). The advantages include a low dosage of radiation, simplified image construction, and good resolution (Nair and Nair, 2007).

6.1 Conventional radiography

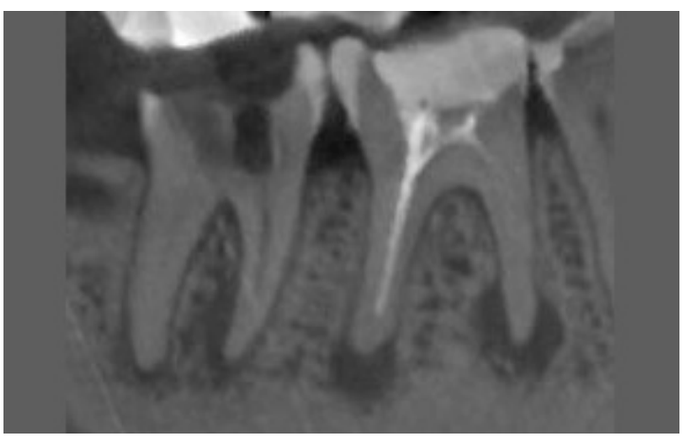
A periapical radiograph of teeth 45–47: This is a 2D depiction from the buccal aspect with a standard level of resolution. Tooth 46 has an inadequate root canal filling and large periapical lesions both mesially and distally. The crown of tooth 47 has been virtually destroyed by dental caries.

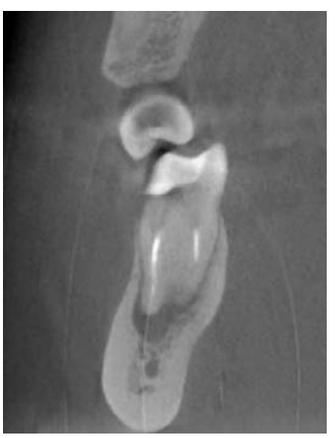


6.2 Volume tomography

A comparable CT view of teeth 46 and 47 clearly demonstrates the differences in image quality between traditional radiography and 3D CT (here, Accuitomo, J. Morita). With CT, the resolution is somewhat lower, but the inflammatory foci are more clearly discernible and actually appear to be larger; this picture more clearly depicts the reality of the situation.

Right: The mesial view illustrates the relationship between the root canal fillings and the apical lesions.

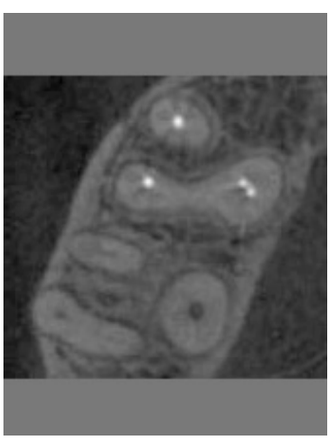




6.3 Sagittal sections

Left: The technique of volume tomography permits the depiction of any desired sectional plane. This image shows the four root canals of a maxillary first molar.

Right: Another image clearly showing the massive osseous destruction below the root tips of a maxillary second molar (courtesy of Dr. Hubert Amschler).

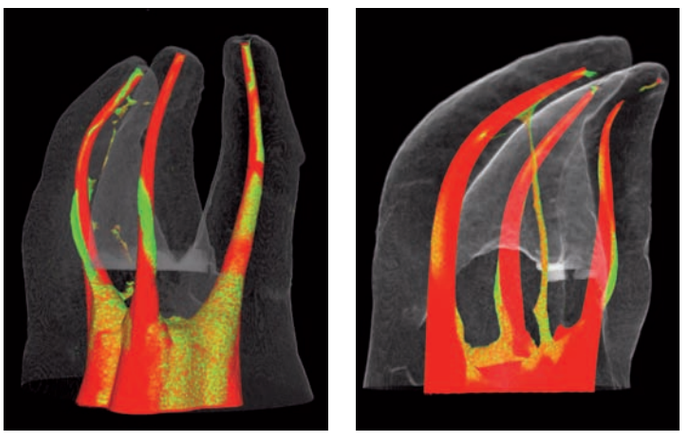


Computed Tomography—Research

CT was developed by Godfrey Hounsfield, and by 1971 had matured enough to be used in practice. The problems of the original high radiation dosage and the low resolution in the millimeter region have long been overcome by a series of technological advancements. Today, laboratory experiments demonstrate a resolution of about 10 µm using axial high-resolution micro-CT (Jung et al., 2005). This level of precision makes micro-CT data comparable with histology (Balto et al., 2000), and permits morphometric analysis of bone, teeth, root canals, and the surrounding tissues (von Stechow et al., 2003).

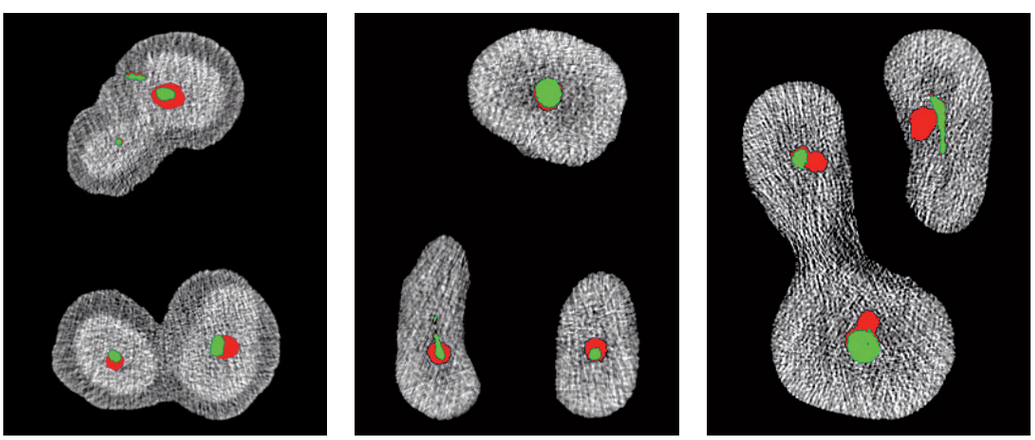
In addition to the initial representation of root canal geometry (Peters et al., 2000) additional work with CT has depicted the efficiency of root canal instrumentation using nickel titanium (NiTi) files (Bergmans et al., 2001; Peters et al., 2001, 2003). These studies demonstrated for the first time that only about 70% of all root canal areas were successfully instrumented mechanically, and that the remainder were only reached with irrigation solutions (Peters et al., 2003).

A systematic micro-CT examination of all tooth groups provided the basis for a fascinating interactive CD-ROM (Brown and Herbranson, 2005).



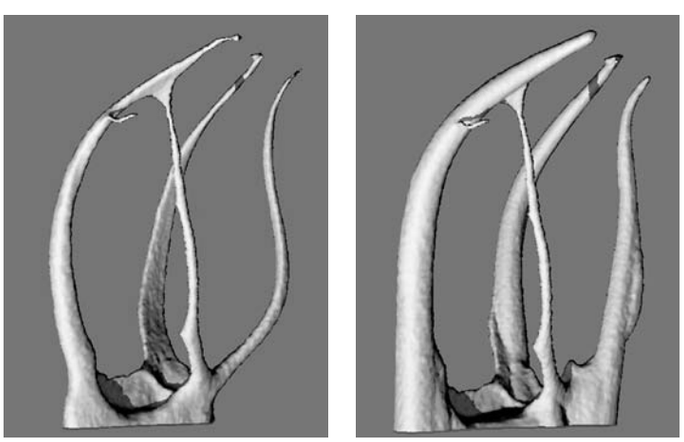
6.4 3D reconstruction

A 3D reconstruction of a maxillary molar scanned with micro-CT. The external surfaces of the tooth are seen as transparent and the root canals are colored. Following instrumentation using FlexMaster (left) or ProTaper (right), the various areas that remained noninstrumented by the files are clearly seen (green: noninstrumented; red: instrumented).



6.5 2D images

Micro-CT data can also be used to portray a 2D image. Using this technology, it is possible to identify in various sectional planes, the continually changing cross section as well as the root contours and the root canals.



6.6 3D depiction of root canals

Following computer calculation and 3D reconstruction from the raw data, it is possible to visually eliminate the external parts of a tooth and display the root canals alone.

Left: Canal width before instrumentation

Right: Canal width following root canal instrumentation using the ProTaper. Note that one root canal (the mb2) was not instrumented (the narrow structure in the middle of the field).

Magnetic Resonance Imaging—Clinical and 3D

MRI was developed in 1973 (Lauterbur) and has been in routine clinical use for over a quarter of a century. In contrast to standard radiographic techniques, MRI does not require the use of ionizing radiation, and has the capacity to accurately depict water and/or fat-containing tissues with high hydrogen–proton components. Traditionally, teeth and bone could not be depicted at all on MRI, or only poorly. Research in recent years has provided ways to overcome these limitations (Baumann, 1995).

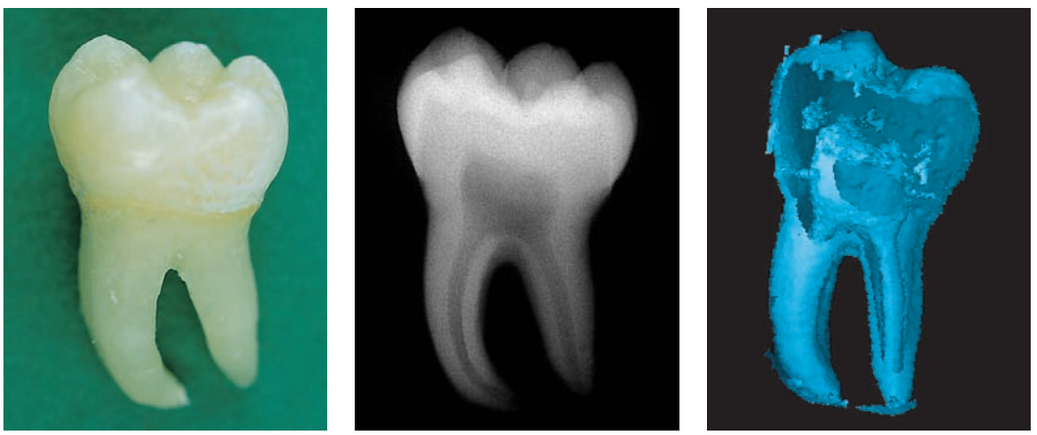
Using special high-resolution spectrometers and a sufficiently high field intensity of 7 Tesla, the first magnetic resonance microscopy (MRM) images were produced (Baumann, 1995; Baumann and Doll, 1997). Improved measurement sequences (constant time imaging, CTI) provided more detailed images (Appel and Baumann, 2002). Clinical imaging of teeth remains difficult because of the small component of hydrogen protons. One measure that has proven effective is to have the patient hold water or an MR-contrast substance in the mouth, to allow use of a higher MR signal (Olt and Jakob, 2004).

6.7 MRM of a mandibular molar

Left: A mandibular molar.

Middle: Conventional radiograph of the molar.

Right: With 3D reconstruction, the external tissues of the tooth can be eliminated electronically, thus permitting a clear view of the internal surfaces of the tooth and the contour of the pulp.

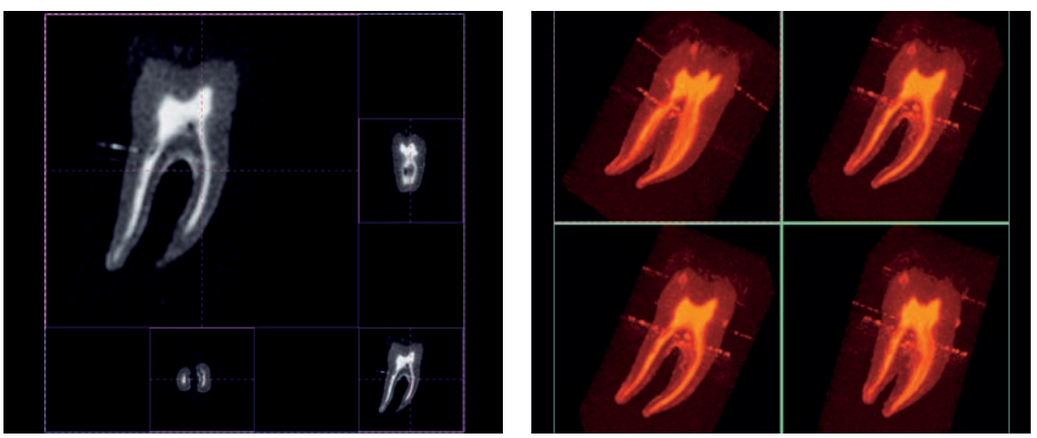


6.8 CTI of a mandibular molar

Constant time imaging (CIT) uses three phase-coded straight lines to rapidly create a sharply depicted image.

Left: The 2D images perpendicular to each other reveal the anatomic details of a particular level of the mesial root (above, right) and the root canals (below, left).

Right: Four views from the 3D reconstruction illustrate the dimensions of the pulp horns and the expanse of the root canal system.

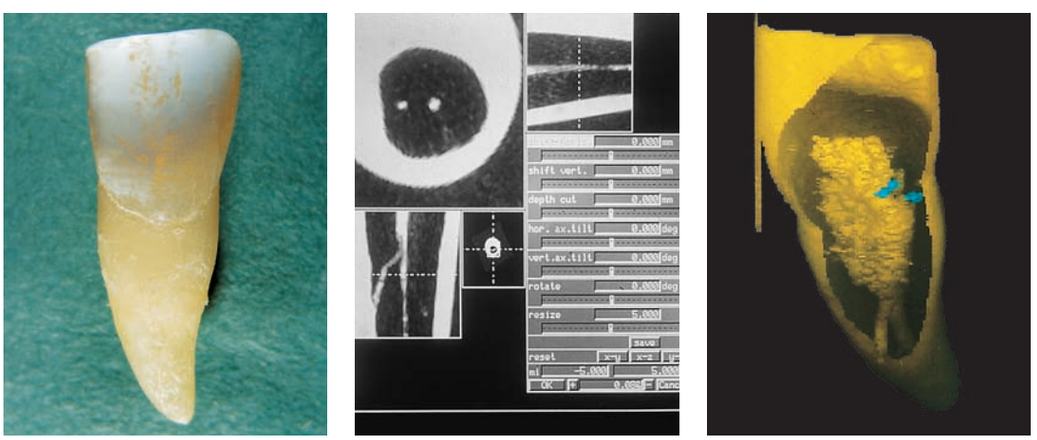


6.9 MRM of an incisor

Left: An incisor.

Middle: 2D reconstruction from the MRM data set. The cross section (upper left) through the root permits assessment of the primary canal centrally and a white spot. A cross-section parallel to the horizontal (below left) shows the course of a lateral canal.

Right: This selected view from the 3D reconstruction clearly reveals the course of the lateral from the main root canal to the labial surface of the root.

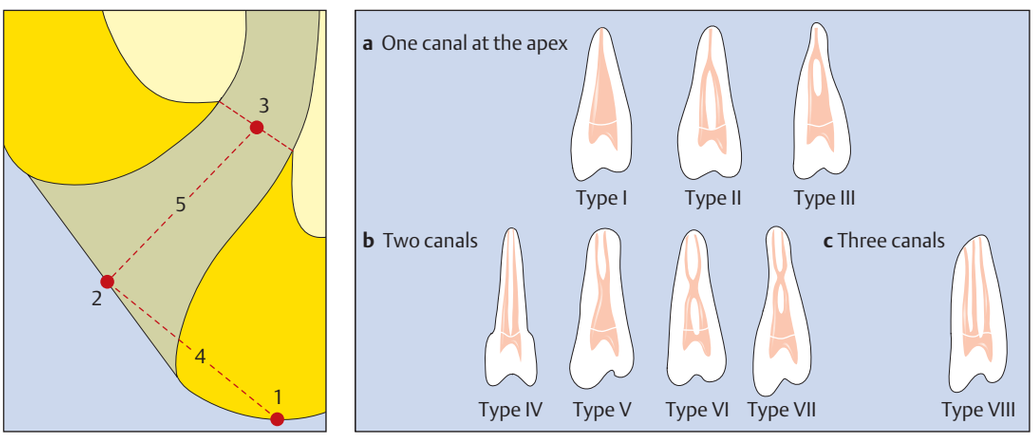


Important Variations in Dental Anatomy

With the widespread use of the clinical microscope, more and more dentists are becoming aware of the huge anatomic variations within the root canal systems. This reiterates the importance of classification systems, for instance the systems according to Weine, Ingle, or Vertucci (1984). A myriad of features—accessory canals, lateral canals, pulpo-desmodontal canals, C-shaped canals, multiple foramina, arborization, deltas, connections between and among canals—are now recognized, and must always be considered during root canal instrumentation and filling.

The classification of the degrees of difficulty of endodontic treatment according to Ingle (1996) is as follows:

- Type I: Insignificant curvature of the root canal
- Type II: Anatomic problems such as severe dilaceration, a complex apical region with divergence or arborization of the canal, with numerous foramina
- Type III: Open foramen, incomplete root formation
- Type IV: Deciduous teeth, resorption of the root tip



6.10 Root canals and the apex

The classification of root canals according to Vertucci (1984) into eight types is helpful in clinical practice.

Left: The schematic depiction of the apical region by Kuttler (1955) is still today the "classical" picture, even though numerous variations exist (**1** radiographic apex [RA], **2** anatomical apex [AA], **3** physiologic foramen [PF], **4** distance AA-RA, **5** distance AA-PF; approx. 0.5–1 mm).

In addition to the macroscopic anatomy of a root canal, the fine microscopic features of the apical root canal that can include initial dimension of 60–100 µm play an increasingly important role. The microscope permits searching for, and visualization of, the smallest files (size 6).

In simple terms, the root canal is a structure resembling a tapered tube. It is widest at the coronal end (pulpal orifice) and narrowest at its apical end, which is formed by a constriction about 1 mm proximal to the apical foramen, the *physiologic foramen* (Kuttler, 1955).

Research studies and practical clinical experience have shown, however, that the pulp canal orifice is often narrowed due to the deposition of tertiary dentin and an apical constriction is present in only about 50% of teeth. In addition, in the apical region of the root, the canal walls are parallel, not tapered, and many root canals, as well as the physiologic foramen, are oval and not round (Wu et al., 2000; Briseño-Marroquin et al., 2004). Briseño-Marroquin et al. (2004) demonstrated that the frequency of occurrence of accessory foramina in the mesial roots of maxillary molars was 33% and in the mandibular molars 26%.

More than 30 years ago, Kerekes and Tronstad (1977) demonstrated that there were significant differences in the width of the apical portions of root canals, with variations from 0.3–0.4 mm to 0.7–0.8 mm within 1 mm of the apical opening of the root tip.

Maxilla								
Distance from the root apex	I1	I2	C	PM1	PM2	Molar		
						mb	db	pal
1 mm	#30–45	#20–60	#20–45	#15–70	#35–70	#10–40	#10–40	#15–340
5 mm	#45–90	#30–100	#30–70	#45–300	#300	#30–300	#20–120	#20–520
Mandible								
Distance from the root apex	I1 oder I2		C	PM1	PM2	Molar		
						mes	dis	
1 mm	#15–70		#10–80	#35	#40	#15–220	#20–60	
5 mm	#30–130		#130	#220	#150	#30–500	#40–240	

6.11 Average diameter of root canals

In a series of three publications, Kerekes and Tronstad (1977) described the physiologic diameter of the root canals of all tooth groups. Their data demonstrated a large range of variation. One of the most important observations was that even 1 mm from the root tip considerable variation in canal widths can be expected and must be given consideration during canal instrumentation and filling.

Maxillary Anterior Teeth

All maxillary anterior teeth have one root and one canal. Therefore, these teeth are type 1 according to the Vertucci system. Exceptions to this rule are extremely rare. For endodontic treatment, the direction of approach to the root canals in these teeth is parallel to the long axis of the tooth; the root canal normally courses obliquely toward the distal.

The pulp chamber is significantly wider in the buccolingual direction than in the mesiodistal (md) direction. This must be considered during canal instrumentation.

The coronal pulp in a young tooth is close to the incisal edge and has three pulp horns in the maxillary central incisor and two pulp horns in the maxillary lateral incisors. Any existing overhang of the pulpal roof must be removed to avoid subsequent tooth discoloration.

In older patients, the roof of the pulp chamber is often first encountered in the region of the tooth cervix. For this reason, the access cavity must often be made near to the incisal edge to achieve the necessary straight-line access to the root canal.

The lateral incisors generally have an oval canal and the root is frequently bent either buccally or distally. Therefore on the radiograph the canal can appear shorter than it actually is.

6.12 Maxillary incisor

For endodontic treatment, the opening in the maxillary incisors is made on the palatal aspect. The coronal pulp chamber is large and wide. Therefore, during access cavity preparation, it is important to make sure that all soft-tissue remnants are removed.

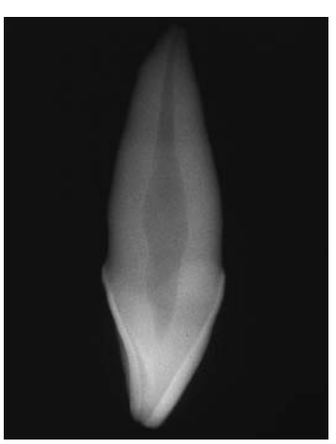
6.13 Maxillary incisor

In addition to a large coronal pulp, maxillary incisors may have a wide or narrow root canal, depending on the age of the patient.

In the apical portion, the canal divides into branches in a deltalike fashion, which can be successfully filled using the thermoplastic technique.

6.14 Maxillary canine

In contrast to the incisors, the root canal in canines is quite voluminous even in the middle third of the root, becoming much narrower only in the final third near the apex. This anatomic feature must be given due consideration during root canal instrumentation and filling.



Mandibular Anterior Teeth

The mandibular anterior segment can be difficult to treat because most mandibular incisors and canines have only one root and one canal (type I; 60%; Rankine-Wilson and Henry, 1965). However, according to Benjamin and Dowson (1974), 25%–41.4% of cases have two root canals that merge in the middle third of the root (type II), or continue as separate root canals to the apex (type IV: up to 5.5%).

Mandibular incisors are delicate. In addition, the teeth are very narrow mesiodistally and can show areas of indentation. The single root canal is straight, but located more labially and may curve distally or, less frequently, labially.

If a second root canal exists it will be positioned further lingually and is generally clearly curved. For this reason, it may be necessary to include the incisal edge in the preparation or completely remove the crown (Hülsmann, 1992). According to Peters (1992a), there are several clues as to the existence of a second canal:

- The pulp chamber is not positioned centrally.
- An instrument within a located canal will be bent and directed laterally without touching the incisal edge.
- In an eccentric radiograph taken from the mesial or distal aspect (20–30°), the instrument will not appear to be centrally positioned within the tooth.

6.15 Mandibular incisor

Left: From the orthograde direction, the mandibular incisor appears quite thin, with a single, almost straight, root canal system (from Reuver, 2005a).

Right: The proximal view of the tooth (which is not possible to see clinically) clearly reveals the wide root canal system with extensive branching that is virtually inaccessible using standard mechanical methods (from Reuver, 2005a).

6.16 Mandibular incisor

Left: The mandibular anterior teeth present particular challenges for endodontic treatment because of their small size.

Middle: The pulp chamber is usually opened in the center from the lingual aspect. About 20% of all mandibular teeth have a second root canal. The clinician should carefully search for a possible second canal orifice at the lingual aspect.

Right: On this extracted tooth, the two canals filled with gutta-percha are clearly evident. The canals have merged the apical region.

6.17 Mandibular canine

In every endodontic laboratory exercise, anatomic variations of root canal size and shape are identified and successfully "treated."

Left: The radiograph shows two divergent root canals in a mandibular canine.

Right: Radiographic appearance following root canal filling.

Maxillary Premolars

All maxillary premolars have two prominent pulp horns beneath the cusp tips; during access cavity preparation these pulp horns may be confused with the actual canal orifices. The mesial concavity results in the danger of a lateral perforation during instrumentation. All the typical features of the first premolars are rare in second premolars and vice versa. A preoperative radiograph is often helpful because in a single-rooted tooth with only one canal, the pulp space will be clearly visible. In premolars with two canals—within one or two roots—a definitive radiographic picture of the canal is limited to the cervical area (Peters, 1992b).

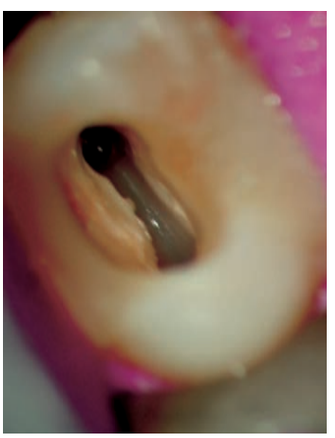
The *first premolar* typically possesses two well-formed roots (56%). The root usually splits into two in the middle third either buccally or palatally. About 40% have only one root but with two root canals (type IV), which end together at a single apical foramen. Three-rooted first premolars are rare (4%) and often have three root canals and three separate apical foramina (type VIII, Vertucci and Gegauff, 1979). These are similar to maxillary molars, whereby in two canal teeth the canals are located buccally and palatally.

Besides the above-mentioned number of roots, the number of canals per root is more relevant for endodontic treatment: Types I and II at 8% or 18% are rare. Most frequently, the clinician finds two completely separate canals (69%), and rarely three. With an average length of 21 mm, the first maxillary premolar is somewhat shorter than the second premolar.

6.18 Maxillary premolars

Left: Maxillary premolars usually have two separate roots containing two separate root canals. The pulp horns are often quite pronounced (courtesy of Dr. F. Paqué).

Right: If the usual two canals exist within two fused roots, one may expect intercommunicating canal systems with arborization (clearing technique) (Reuver, 2005b).



6.19 Maxillary premolars

Left: The pulp horns of the premolars are often located high within the crown.

Middle: The dentin layer between the two roots must be removed in order to expose the subjacent coronal pulp.

Right: The actual canal orifices will often be found several millimeters deeper.

The *second premolar* typically has a single root with a single canal. Less frequently, one encounters second premolars with two roots, each with a separate root canal. With regard to canal configuration, type I is dominant (48%). Types II and IV–VII, according to Vertucci, are encountered with equal frequency. With age, the height of the coronal pulp decreases in the area of the pulpal horns and the pulpal roof (secondary dentin). The floor of the pulp chamber, however, remains at the level of the tooth cervix.

The roots of maxillary premolars may be curved in all possible directions, and often exhibit two bends. Even in premolars with two canals of the same endodontic working length, the variation in position and therewith the canal length can present clinical problems. In such cases the clinician has two options.

- Take eccentric radiographs: If the cone of the x-ray machine is shifted horizontally (eccentric exposure), according to the "buccal object rule" the objects nearest to the film (palatal canal) will move less compared with those structures distant from the film (buccal canal).
- Place files of two different types (e.g., K and Hedström (H) files) in the canals. These can be clearly differentiated on a radiograph due to their different surface texture.

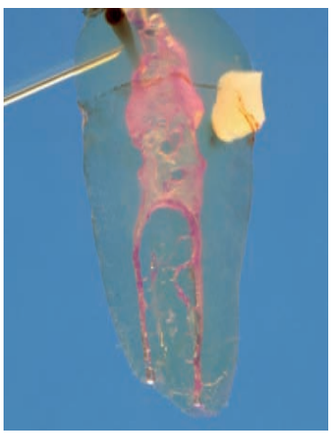
Mandibular Premolars

In comparison with mandibular anterior teeth, mandibular premolars have a cantilevered crown, suggesting that these teeth have a much larger root. However, the roots of the mandibular premolars are actually quite delicate and small, with a mesial depression and a profile that is primarily oval; the broadest width is in the buccolingual direction.

Because of the normal lingual tipping of mandibular teeth and the small lingual cusp of the premolars, access cavity preparation should be carried out from the buccal aspect toward the central fissure. The opening into the pulp chamber should be oval in shape, following the shape of the respective canal. The coronal pulp is wide, with a larger buccal and a smaller lingual pulp horn.

The canals of both mandibular premolars are similar in shape and quite wide in the buccal direction up to the region of the middle third of the canal. The apical one-third of the root canal, however, is quite narrow. Both mandibular premolars have, in most cases, a single root and a single canal. Nevertheless, with mandibular first premolars the clinician must be prepared to find two separate root canal orifices in about 25% of cases.

An acute exacerbation in a case of apical periodontitis may lead to transitory paresthesia of the mental nerve.



6.20 Mandibular premolars

Left: Mandibular premolars normally have one root and one root canal, but variations may include teeth with two roots and two root canals (clearing techniques) (Reuver, 2005b).

Right: The buccal pulp horn is much larger and more pronounced, and extends further coronally.

6.21 Radiographic depictions

Left: Lateral radiographic view of an extracted mandibular premolar showing the wide pulp cavity. The buccal pulp horn is particularly pronounced with respect to the lingual horn.

Middle: Pronounced periapical lesions in teeth 43 and 44.

Right: Following endodontic treatment of the two teeth, there was marked bone fill after only 6 months.

The mandibular first premolar can present difficulties during endodontic instrumentation, because the single canal in almost 25% of cases splits in the apical third of the root into two separate canals (Pineda and Kuttler 1972; Vertucci, 1978), according to the canal configurations as described by Vertucci (types IV and V).

From a practical point of view, this means that the access cavity preparation should be extended lingually to achieve ideal access to the root canal.

The single canal, which is straight in the coronal half of the canal, is often considerably curved distally, either in the lingual or buccal direction. For this reason, the files for instrumenting the buccal portion of the canal should be inserted from a lingual approach, and for the lingual aspect from a buccal approach. Care must also be taken to avoid the danger of artificially straightening the canal or excessive widening of the delicate apical third of the canal. A small number of first premolars will be of type II/III (< 5%). Less than 2% have three canals (Hülsmann, 1994).

The second mandibular premolar shows very few variations (2.5%) of types II, IV, and V. Almost always (97.5%) one encounters a single root with a single root canal. Less than 1% have three canals, and such presentations are extremely difficult to instrument.

Maxillary Molars

Maxillary molars present the greatest clinical challenge for endodontic treatment. This is because the complexity of the root canal system surpasses that of all other teeth within the human dentition (Peters, 1992c).

The maxillary molars usually have three roots, which contain four root canals, as described as early as 1915 by Moral (Rostock): "A fourth canal or a separation of the pulp chamber in the sense of the existence of a fourth canal will be observed in 63% of maxillary molars."

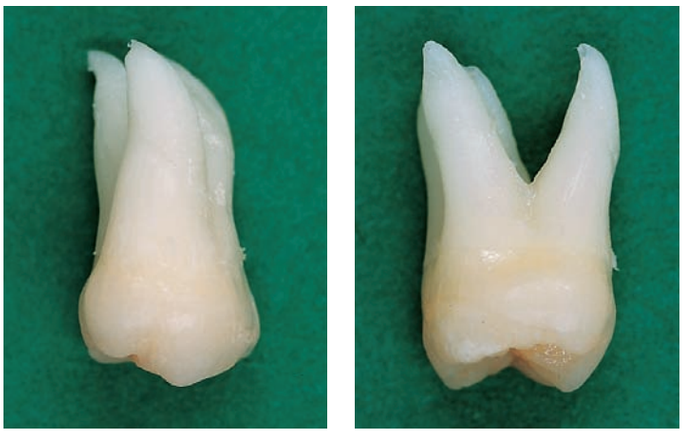
The two canals of the *mesiobuccal root* are oriented in the buccolingual direction, so that it is often necessary to use a distal eccentric radiographic projection to depict the individual canals. The *distobuccal root* is the shortest, usually exhibiting a single canal in the middle of the root. This canal is often first curved distally and then mesially in the apical third of the root. The orifice is usually located centrally rather than distally within the pulp chamber.

The *palatal root* is the longest, has the largest lumen, and is often buccally dilacerated in the apical third. The root canal often opens into the periodontal ligament space on the palatal surface of the palatal root. This fact contributes to the frequent misinterpretation of root canal length on traditional radiographs.

6.22 Complexity of maxillary molars

Left: This palatal view of an extracted maxillary molar shows the standard image of a single massive root. The root tip is bent distally, giving the impression that the entire root canal system is curved.

Right: In this distal view, the two buccal roots and the palatal root appear widely separated. Note that all of the root tips are bent buccally.

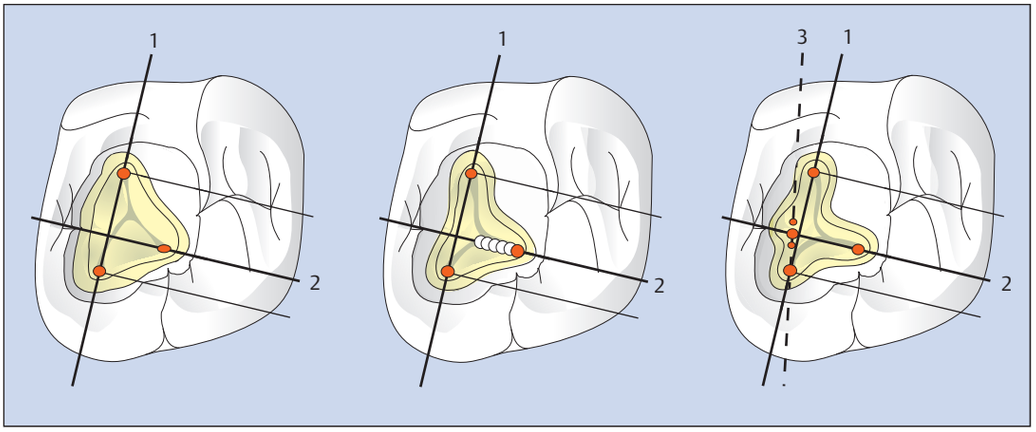


6.23 Geometric lines

Left: A primary aid is line 1 between the mesiobuccal and palatal cusps with correspondingly named canals. A perpendicular to line **1** (line **2**) drawn at one-third the width of the crown from the distal surface passes through the distobuccal canal.

Middle: The distobuccal canal can lie along line **2**. In M1 the canal is further from line **1**, at M2 significantly further mesially.

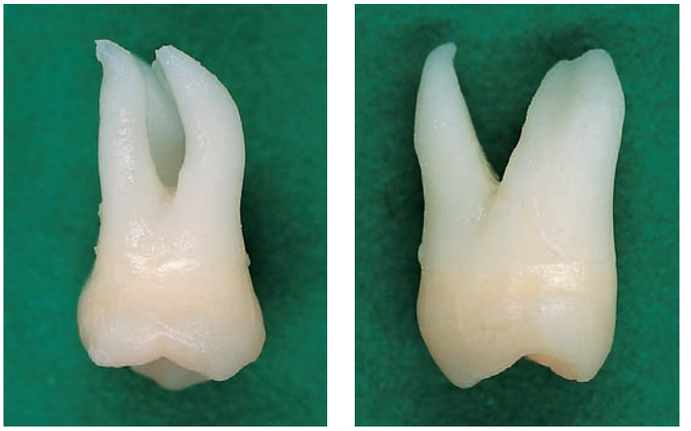
Right: The frequently encountered fourth mesiopalatal canal lies mesial to the intersection of lines **1** and **2**, about 10° from line **3**.



6.24 Complexity of maxillary molars

Left: This buccal view shows the standard image of two individual buccal roots, whose tips are curved distally. Mesially, a larger radius of curvature extends equally over the root tips, while distally only the final 2 mm of the root tip appears bent.

Right: The mesial view shows the mesial and palatal roots fused together.



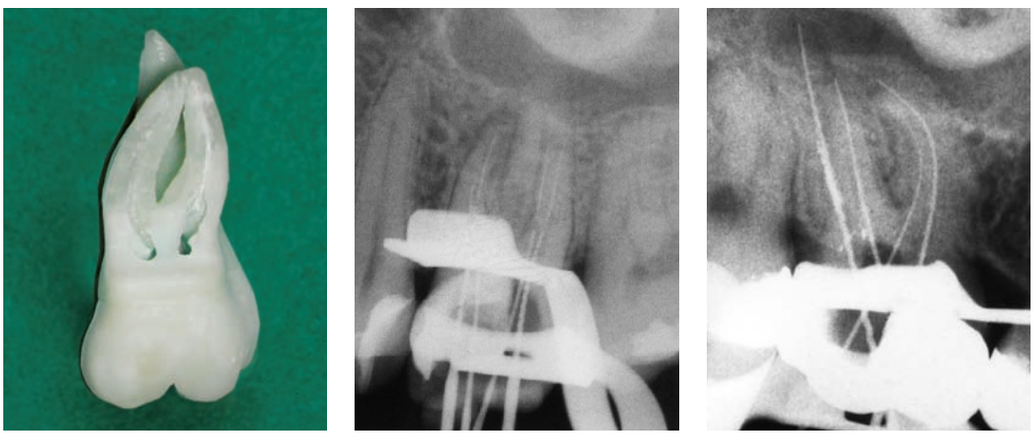
Peculiarities of Maxillary Molars

Access cavity preparation in maxillary molars should begin in the central fossa and extend in the palatal direction (the pulp cavity is wide in this region, and easy to detect). Formerly, it was recommended that the access opening should be trapezoidal in shape, but today it is recommended that the access opening is more like a rounded triangle or even a complex shape to save as much hard tooth substance as possible (see Fig. 6.23).

In older individuals, or in patients with considerable tertiary dentin, the pulp chamber is reduced in size, which makes access cavity preparation and detection of the individual canal orifices more difficult. Developmental depressions and discoloration of the pulpal floor should be used as clinical guides. Seventy-five percent of all maxillary molars have accessory canals, and these may serve as niches for bacterial colonization.

Because of the greater use of microscopes in endodontics, additional canals (e.g., mb3, db2, or pal2) are increasingly being identified and treated.

The *second maxillary molar* is very similar to the first molar, but is smaller and exhibits less divergence of the roots. The distobuccal canal is usually detected more mesially, compared with the first molar. The *third molar* exhibits an enormous variety of shapes, sizes, and root canal configurations.

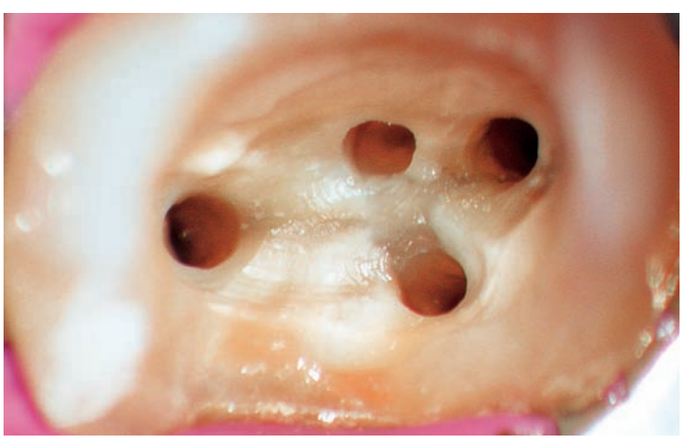


6.25 Peculiarities of maxillary molars

Left: An unconventional longitudinal section through the buccal roots of a maxillary molar reveals an instructive view of the shape of the canals.

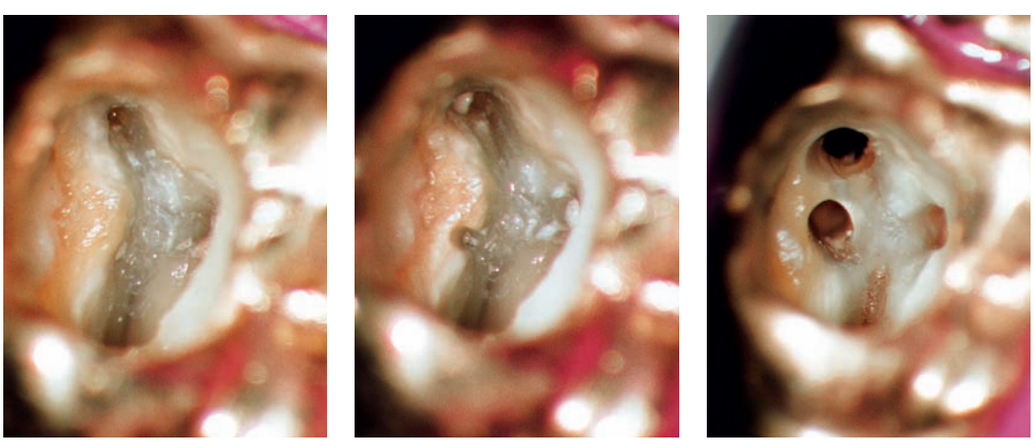
Middle: In the orthoradial radiograph, mb1 and mb2 usually cannot be differentiated. In this vertical radiographic projection, the wing of the rubber dam clamp is superimposed.

Right: A distal eccentric radiograph permits visual separation of all four root canals. The first and second mesiobuccal canals are completely separate.



6.26 Maxillary molars may typically have four root canals

The spatial relationships of the four root canal orifices are clearly depicted in this clinical photograph. The depressions and dark color of connecting lines on the floor of the pulp provide clues about the location of the individual orifices.



6.27 Step-by-step opening of the orifices

Left: Immediately after access cavity preparation, the canal orifices appear small, and are difficult to detect even microscopically.

Middle: Following initial opening using hand files, the orifices are easier to detect.

Right: Following successful instrumentation, mb1 and mb2 (left above) as well as db can easily be visualized (right). The palatal canal orifice lies below.

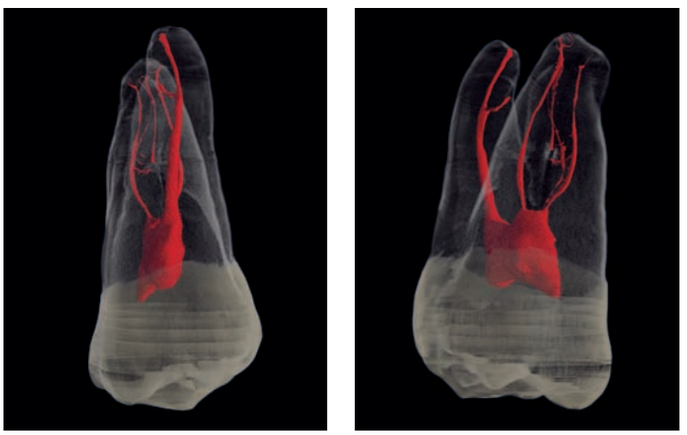
Maxillary Molars

The mesiobuccal root of the maxillary molars has a complex architecture. Kidney-shaped and in some instances more voluminous than the palatal root, the mesiobuccal root contains at least two root canals.

In the 1970s and 1980s, the frequency of a second mesiobuccal canal (mb2) was estimated at 18%–33%; subsequent in vitro studies revealed the rate of occurrence to be 52%–95.2%, and most recent in vitro work estimates 16%–78% (Görduysus et al., 2001).

More extensive use of the clinical microscope has contributed to the discovery that not only a fourth canal but other additional canals also exist. The reason lies in the knowledge of the fourth canal itself. According to Stropko, (1999), today's endodontist can use ultrasonic devices as well as exploit the shadow-free resolution and magnification of the clinical microscope for successful exposure of root canal orifices.

Even dental students will be able to locate the small mb2 canal orifice in almost half of all maxillary molars. It must be kept in mind, however, that about 16% of such canals cannot be effectively instrumented and sealed because the second mesiobuccal canal is often sharply curved, or highly calcified compared with the first mesiobuccal canal, and is difficult to access, particularly in older patients (Thomas et al., 1993; Baldassari-Cruz et al., 2002).



6.28 Maxillary molar, 3D views

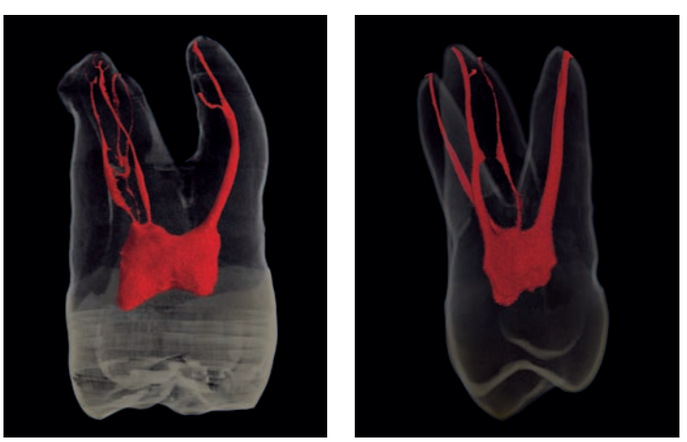
Left: Buccal aspect of a molar scanned using micro-CT at a resolution of 10 µm, and then reconstructed three-dimensionally.

Right: The distal projection provides a view of the palatal root canal giving of branches in the middle third of the root (courtesy of Dr. F. Paqué).

6.29 Multiple foramina

After staining an extracted maxillary molar, the multiple apical foramina on the mesiobuccal and distobuccal roots are clearly visible.

Right: The transparent preparation of the same tooth clearly illustrates the four apical foramina and their relation to both of the primary canals within the mesiobuccal root (Reuver, 2005b).



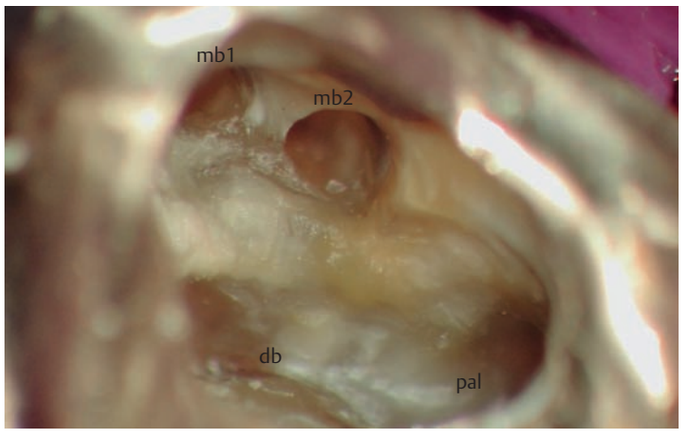
6.30 Complexity of the canal system

Left: This mesiodistal projection provides a view of the first and second mesiobuccal canals, which begin at two separate orifices.

Right: This mesiodistal view of another maxillary molar shows the first and second mesiobuccal canals initially following a common course before they divide into two separate canals.

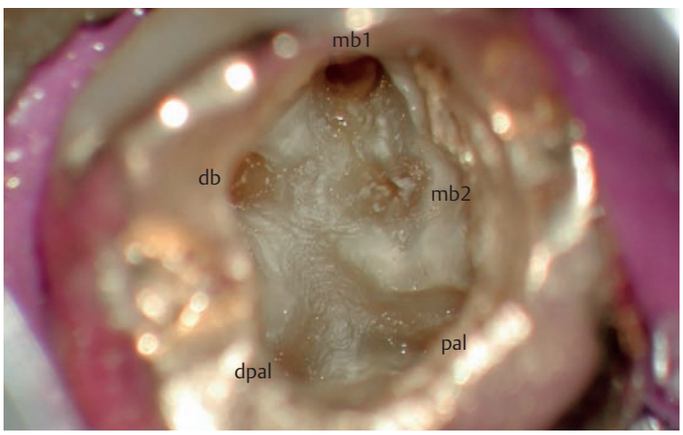
The *distobuccal root* of a maxillary molar normally has a single root canal. However, there are some case reports of a second canal —in some cases even with two separate foramina—in the distobuccal root (Martinez-Berna and Ruiz-Badanelli, 1983; Bond et al., 1988; Hülsmann, 1997). Even the *palatal root* often has more than one canal. In addition to two separate canals with two separate foramina (Slowey 1979; Thews et al. 1979; Cecic et al., 1982; Jacobsen and Nii, 1994), two confluent canals have been described (Thews et al., 1979; Bond et al., 1988).

The maximum number of root canals so far reported in a maxillary molar includes three palatal canals (Wong 1991; Maggiore et al., 2002) and three mesiobuccal canals (Martinez-Berna and Ruiz-Badanelli, 1983; Beatty, 1984) for a total of six canals. In this regard, it is important to note that many studies have limited themselves to teeth from Caucasians whereas other populations such as the Chinese or Africans also exhibit varying canal shapes and canal frequencies (Alavi et al., 2002). The increasing worldwide migration of various populations between continents and the increasing multiracial populations in many countries may necessitate a new clinical approach to previous endodontic generalizations.



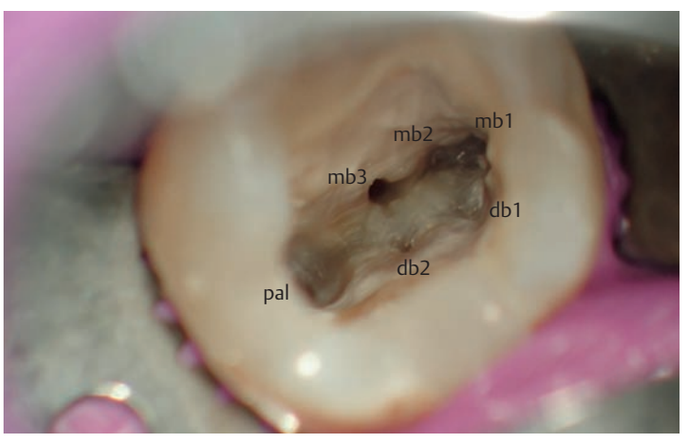
6.31 Molar with four canals

Maxillary molars almost always have four root canals.



6.32 Molar with five canal orifices

This maxillary molar exhibits a rare characteristic: In addition to the usual four canals (mb1 and mb2 [above and middle, right], db [middle, left], and palatal [pal, below, right]), a second palatal canal is visible (dpal, below left).



6.33 Maxillary molar with six canal orifices

This maxillary molar in a southeast Asian patient has an extremely deep pulp chamber. In this mirror image, in addition to the palatal canal (left), there are three mesiobuccal canals (below) and two distobuccal orifices (above).

Mandibular Molars

The *first mandibular molar* has two roots, and the mesial root usually has two canals which end at a single apical foramen in 45% of cases. The mesiobuccal canal is the most difficult to instrument because it is directed first mesially and then distally. The mesiolingual canal is broader and straighter, but may have a mesial curve in the apical region. Numerous anastomoses frequently exist between the two mesial canals (Peters, 1992d).

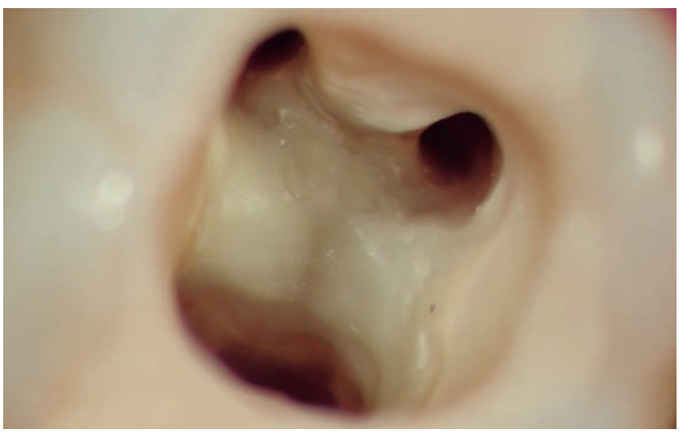
The single distal canal is normally larger, oval in shape, and ends in 60% of cases shortly before the anatomical apex on the distal surface of the root (Tamse et al., 1988). However, more than 25% of all first mandibular molars exhibit two distal canals (Skidmore and Bjorndal, 1971). According to Pineda and Kuttler (1972), type II (13%) and type IV (14%) are about equally represented.

The *second mandibular molar* is very similar to the first molar. However, the roots are shorter, the root canals more curved, and the range of variation higher. In many cases (58%) the clinician will encounter only one or two mesial canals of type II or IV (Pineda and Kuttler, 1972: 21% for both types). In the distal root there is usually a single canal (>94%), and less frequently type II (2.1%) or type IV (3.5%; Pineda and Kuttler, 1972).

6.34 Mandibular molar

In the majority of cases, mandibular molars have two roots (one mesial, one distal). The mesial root generally has two root canals, and the buccal canal is usually narrower and more curved. The distal root most often has one large, oval canal.

Right: The 3D reconstruction of a mandibular molar reveals, in this mesial image, the two canals coursing separately. In the background, the coronal canal system is wider, becoming narrower, and subsequently branching into two apical components which then fuse together.



6.35 Root canal filling, mandibular molar

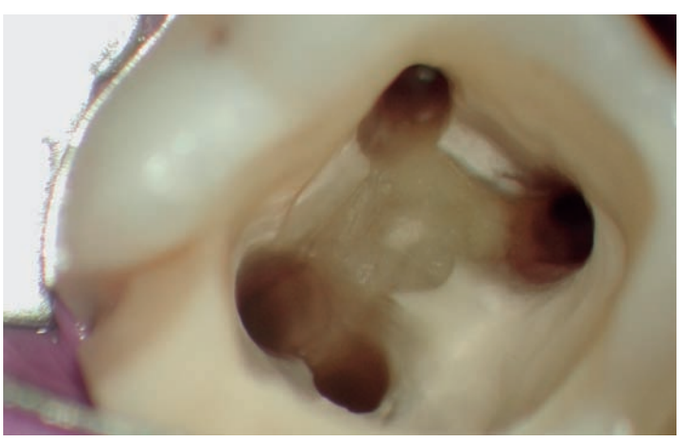
Both mandibular molars show typical configurations: The first mandibular molar often (up to 40%) has a second distal root canal; the second mandibular molar usually has only one canal. Within the second molar, the communicating isthmus between the two canals, with otherwise separate roots, is visible.

Right: The sectioned mandibular molar permits a view of the highly calcified canal lumen. The left canal is severely bent and curving sharply near the apex. A large pulp stone (*) is visible on the floor of the pulp.

6.36 Isthmus and calcifications

An occlusal view of this mandibular molar reveals a wide isthmus between the two mesial roots (white discoloration), as well as dumbbell configuration of both distal canals.

Right: The 3D reconstruction of a mandibular molar with similar canal configuration as in the clinical photo (left).

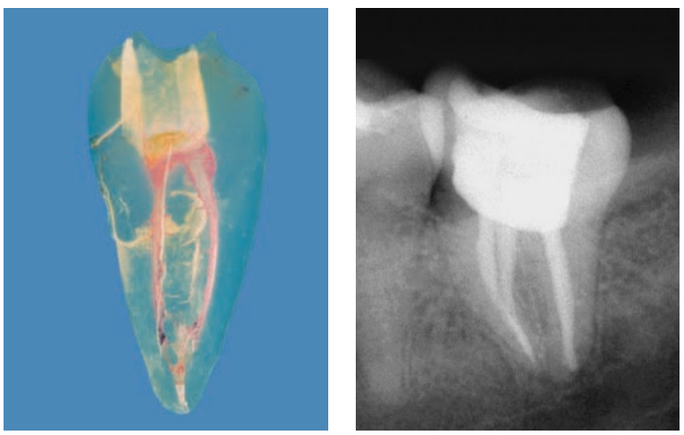


The access cavity preparation for mandibular molars should proceed from the center of the occlusal surface, and extend trapezoidally with the broad base on the mesial margin, thus protecting the distal third of the tooth. As with maxillary molars, pulp stones are often encountered and must be removed before root canal preparation can begin. One may often encounter mesial and distal root canal orifices; the distal orifice is usually more rounded and smaller.

Five pulp horns, which are longer and more pronounced lingually, are also often seen. The dentin overhang at the mesial orifice must be removed to lessen the danger of penetration.

A peculiarity is the so-called C-shaped canals. First described by Cooke and Cox (1979), with an incidence of 8%, they are most often encountered in second mandibular molars, but can also be found in first mandibular molars, premolars, or even maxillary molars. In Chinese populations, the prevalence is 33%–52%.

Clinical signs of the presence of C-shaped canals include continuous pain, persistent bleeding from the root canal and confluent canals. The roots appear tapered or fused on the radiograph (Peters, 1992d).



6.37 Transparent preparation of a mandibular molar

Left: This mesial view of the mesial root shows the confluence of the two mesial canals in the apical third of the root, where a communicating system of root canals exists (Reuver, 2005a).

Right: Frequently, the distal root canal (approximately 60%) exits on the distal surface of the distal root (Tamse et al., 1988).

6.38 Complexity of mandibular molars

Both the mesial root canals often have a number of intercommunicating branches. With increasing age of the patient, internal calcifications will render access and instrumentation of the root canal difficult.

Special Cases

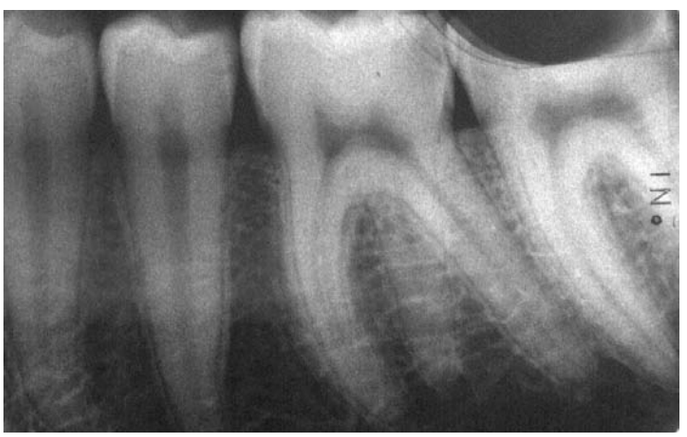
In contemporary endodontology, the clinical microscope has greatly expanded the optical recognition of the finest anatomic structures within the teeth. The discovery, recognition, and definition of secondary root canals, which were previously rare or reconciled to the area of histologic studies, is today a common clinical experience.

It is important that clinicians practicing endodontology familiarize themselves with the myriad of possible root canal orifices, shapes, paths, and branching patterns, as well as their locations, in order to identify each and every root canal and provide optimal therapy.

There are numerous keys to success. Diagnostic radiographs taken before the initiation of therapy will provide clues as to the existence of additional roots and/or root canals. In addition, it is necessary to take radiographs at various projection angles in order to form a visual image of the 3D configuration and position of the root canals. With time and experience, clinicians will develop a "feel" for the detection of hidden structures by following the fine depressions and indentations in the pulpal floor as well as the ability to recognize alterations in color. The "white line" is an example of this "feel."

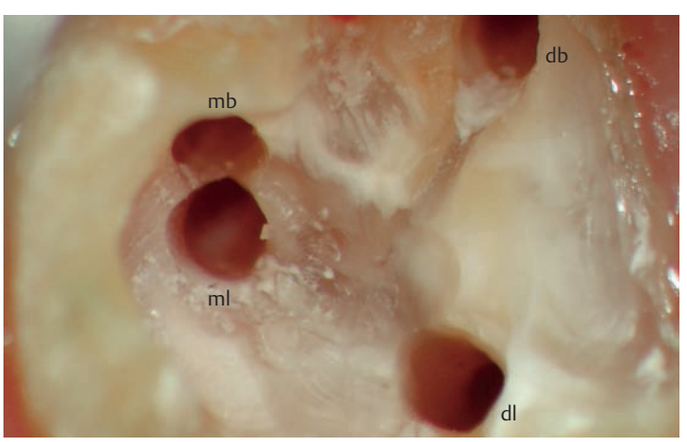
6.39 Diagnostic radiograph

Radiographs are the ultimate key to successful endodontic treatment. In this radiograph, one notes an additional root in a mandibular molar: A true exception to normal mandibular molar anatomy (courtesy of D. Jüsgen).



6.40 Unusual case I, mandibular molar

In this mandibular molar, the two mesial canal orifices are very close together. A distal canal is located in the normal position (below). The dark line and a depression of the pulpal floor are leading to an atypically located fourth root canal (db).



6.41 Unusual case II, mandibular molar

During the revision of a prior inadequate root canal filling in this left mandibular first molar, three intercommunicating root canals were observed mesially. This extremely wide eccentric radiograph also depicts the width of the distal canal rather well.

7 Local Anesthesia

In modern endodontic treatment, dental local anesthesia has a central role in treatment planning. Additional measures such as intravenous premedication, intravenous sedation, or general anesthesia are necessary only in exceptional cases.

However, the various risk factors that may be present (e.g., the increasing number of older patients and those with pre-existing medical conditions or taking long-term medications for systemic conditions) demand an individualized approach that takes the risks into account. Available local anesthetics, vasoconstrictors, and application techniques should be optimally used for each individual patient. At approximately 4.5%, the rate of complication associated with the use of local anesthesia is low, and life-threatening complications are extremely rare (Daubländer, 1997).

Local anesthesia in dentistry involves reversible blockade of stimulus propagation either from the peripheral nerve endings (e.g., infiltration anesthesia, periodontal ligament injection) or at the level of the peripheral nerves (block anesthesia). In addition to their effect on vegetative and sensory functions, increasing concentrations of local anesthetics can cause inhibition or reduction of motor neuron functions and paralysis can occur. At the molecular level this happens through a specific, receptor-mediated blockade of voltage-gated sodium channels of the neuronal axon. This leads to inhibition of formation and further transmission of action potentials. The sodium channels are present throughout the body and represent an important signal conduction system. Therefore, at a sufficiently high systemic concentration, local anesthetics can elicit systemic nerve blockage. Possible consequences are disturbances of the central nervous system and the cardiovascular system.

All local anesthetic solutions have the same basic chemical structure, consisting of three components (Niesel, 2003):

- an aromatic residue that is responsible for the lipophilic characteristics;
- a substituted amino-nitrogen compound, which is hydrophilic;
- an intermediate chain, whose length is responsible for the intensity of the anesthetic effect, and differentiation in esters and amides.

Ester-type solutions are metabolized and rendered nontoxic by cholinesterases in tissues and blood. The amides are primarily metabolized in the liver. For injectable solutions only amides should be used, whereas esters are still appropriate for superficial anesthesia (tetracaine or benzocaine) (Malamed, 2004).

Local anesthetic solutions must change their charge potential twice in order to reach the receptors on the inner surface of the nerve membrane. The local anesthetic molecules can only diffuse in their basic state. Local anesthetic solutions exist as hydrochloride compounds. Therefore they have to be neutralized by local tissue buffers to achieve a basic and diffusion-capable state. Following penetration of the multilayered neuronal membrane, the molecule releases the accumulated hydrogen ions, and then remains nonprotonated and can interact with the receptors.

Depending upon the diameter of the nerve and the presence of a myelin layer, a sequence of nerve blockade occurs. Clinically, pain and temperature sensitivity (C- and Aδ fibers) is blocked.

Local Anesthetic Solutions (Amides)

Lidocaine is a common local anesthetic and antiarrhythmic drug that is used worldwide; it is also the oldest amide preparation. Lidocaine is typically used as a 2% solution with epinephrine as vasoconstrictor (usually 1:100 000). It should be available as an alternative local anesthetic.

Articaine has potency similar to lidocaine, but is less toxic because it is metabolized primarily in the tissues and blood. For dental use, it is available as a 4% solution with and/or without epinephrine. Because of its high protein-binding capacity, it is also indicated for use in pregnant women. An epinephrine concentration of 1:200 000 or 1:400 000 is sufficient for routine dental procedures.

Mepivacaine can be used without a vasoconstrictor because it possesses certain vasoconstrictor effects. It should be used as a 3% solution, but has a relatively short period of efficacy.

Bupivacaine, the most potent but most toxic local anesthetic drug, is effective up to 6 hours even without epinephrine. Therefore it is indicated for long-term anesthesia and pain control.

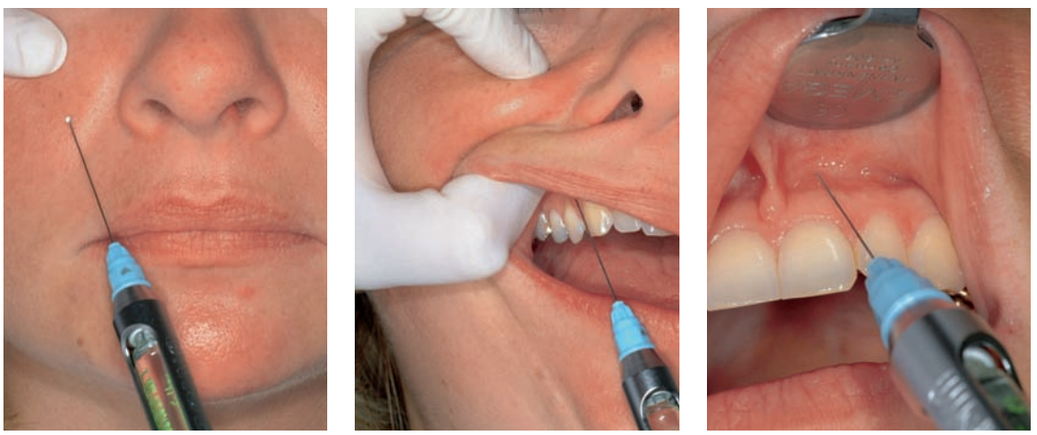
Maxillary anesthesia

7.1 Block anesthesia of the infraorbital nerve

Left: Extraoral injection site.

Middle: Intraoral technique (injection). It is important to palpate the infraorbital foramen as the needle is inserted. With this intraoral approach the canine is the primary landmark for both the choice of injection site and the direction of insertion of the needle.

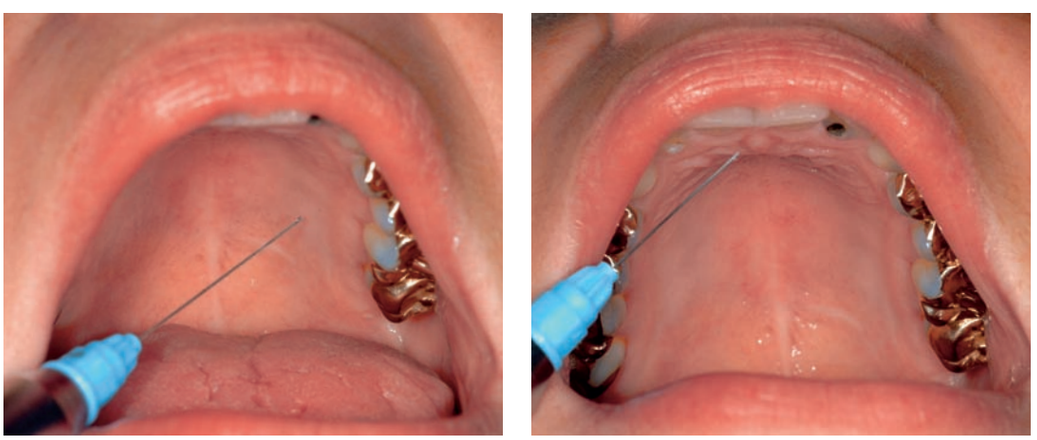
Right: Infiltration anesthesia in the labial region.



7.2 Nerve block anesthesia

Left: Block anesthesia of the nasopalatine nerve. The direction of entry of the needle is from the corner of the mouth on the opposite side and it is inserted until contact is made with the bone.

Right: Block anesthesia of the nasopalatine nerve. Approaching from the opposite side of the mouth, the needle is inserted adjacent to the papilla only a few millimeters deep.



Vasoconstrictors

Since virtually all local anesthetics lead to vasodilation, a vasoconstrictor should be used along with them, as long as there are no contraindications. This improves the depth of anesthesia and lengthens the therapeutic period of efficacy, while reducing reabsorption and therefore limiting the systemic plasma levels. The agent of first choice is the catecholamine epinephrine. Octapressin has a delayed and weaker effect; epinephrine no longer used in this regard.

Additional Components

All solutions that contain a catecholamine as vasoconstrictor will also contain sodium disulfide as an antioxidant. Allergic reactions in patients with asthma can occur. The commercially available ampules do not contain any additional ingredients for preservation or stabilization.

Clinical Choices

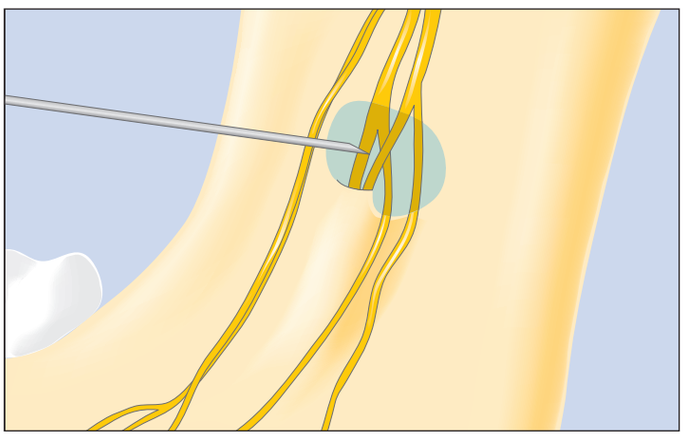
The individual components of a local anesthetic injection should be combined, keeping in mind the patient's medical history, the anticipated treatment procedure, the anticipated technique, and the local anesthetic solution being used (Daubländer, 1999).

Technique

If *superficial anesthesia* is intended as the only form of anesthesia, it can be applied over a relatively large surface area. If the mucosal injection is intended to eliminate pain and also act as a local disinfectant, it should be applied only in the immediate vicinity.

Infiltration anesthesia is extremely effective (failure rate approximately 5%). It is the most frequently used anesthetic technique, primarily in the maxilla. Infiltration anesthesia may also provide sufficient pain relief in the mandible for endodontic treatment mesial to the mental foramen. With the use of high concentration local anesthetic solution (3%–4%), infiltration anesthesia can also provide sufficient pain relief in the palatal alveolar process.

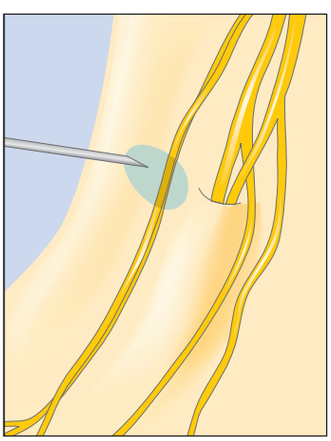
With *nerve block anesthesia* the entire peripheral nerve is affected. With a relatively small amount of local anesthetic solution a large area can be anesthetized. Especially with a nerve block anesthetic injection near the mandibular foramen, one can achieve inhibition of sensory symptoms (lingual nerve and inferior alveolar nerve). The needle itself should never be inserted directly into the foramen or the bony canal.

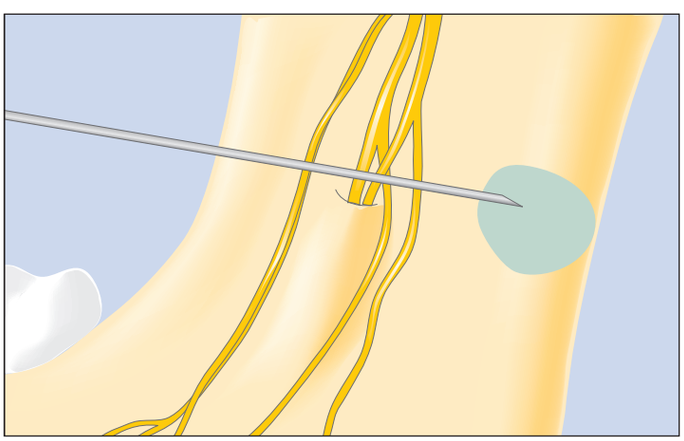


7.3 Inferior alveolar nerve block

If the needle is positioned properly, the local anesthetic solution will be deposited directly above the lingula and the foramen; this permits the anesthetic to reach the inferior alveolar nerve and the lingual nerve by diffusion.

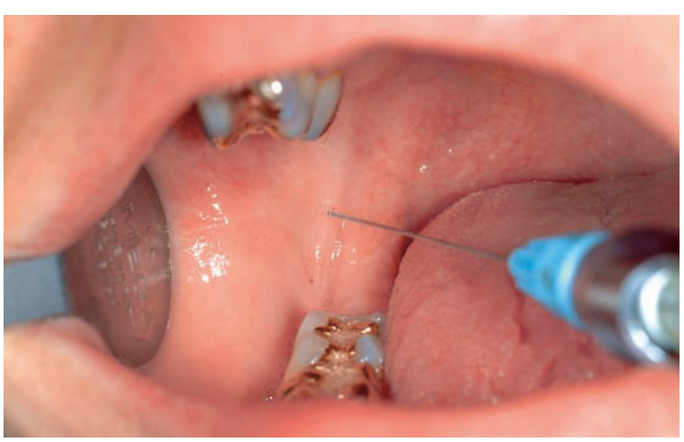
Left: If the lingula of the mandible is pronounced, this injection may be rendered more difficult clinically.





7.4 Failure to achieve anesthesia because of incorrect injection technique

If the tip of the needle is too far anterior with respect to the foramen (left), insufficient anesthesia will be the result. If the needle is inserted parallel to the ascending ramus of the mandible and the tip goes beyond the foramen, not only will there be a failure of effective anesthesia, but some degree of partial facial paralysis can result.



7.5 Inferior alveolar nerve block

At the mandibular sulcus, above the foramen, 1–1.5 mL of anesthetic solution is deposited. Approaching from the canine/premolar region of the opposite side, the needle is positioned approximately 1 cm above the occlusal surface, anterior to the pterygomandibular raphe and inserted approximately 1.5–2 cm until bony contact is made.

Periodontal ligament injection can be used for single-tooth treatment or for enhancing the anesthetic effect if previous anesthesia has not provided adequate pain reduction. Because of the raised reabsorption rates (cf. intravenous) the volume of the injection and vasoconstrictor amounts should be limited.

In special cases (particularly inflammatory pulpal conditions), *intrapulpal* and/or *intraosseous* injections may be required. High reabsorption rates must be taken into account in this case as well. Injection directly into infected tissues should be avoided, and in such cases extraoral anesthetic injections may be indicated.

Side effects

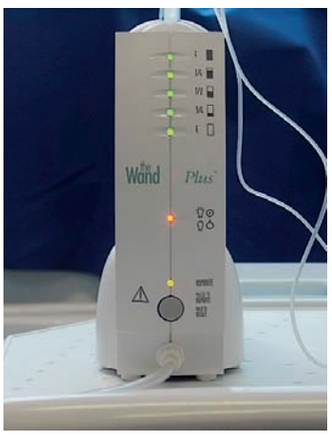
In addition to specific side effects related to overdose of local anesthetic agents or vasoconstrictors, nonspecific complications that may result from the patient's feelings of fear, stress, or pain must also be considered. These are most often vasovagal syncope and the hyperventilation syndrome. Local complications are usually of a transient nature; however patients must be informed that any nerve damage may be permanent. In any case, the entire dental treatment team must be well-trained in the event of possible adverse effects.

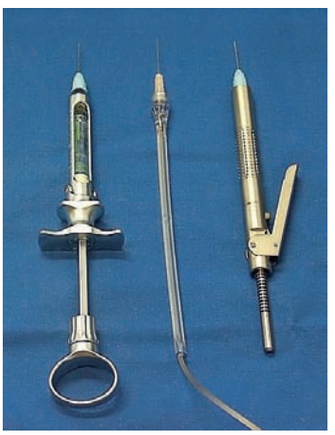
7.6 Armamentarium

Left: Computer-assisted injection technique, which regulates the speed of injection depending upon the pressure within the tissue (The Wand plus).

Middle (from left to right): Injection syringe for use with passive aspiration, handpiece of the computer-guided injection device, intraligamentary injection syringe.

Right: Plastic, single-use carpule holder with a cover that can be removed with a single forward motion to prevent needle-stick injury (VarioSafe).

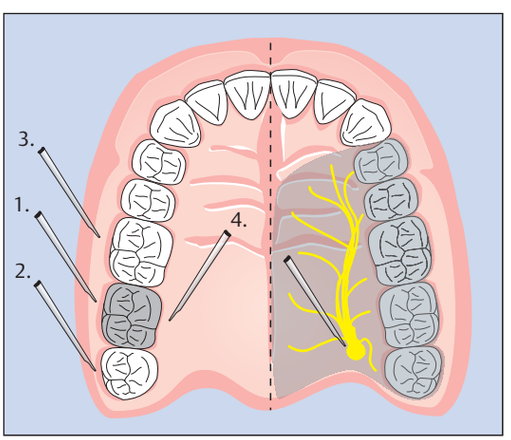


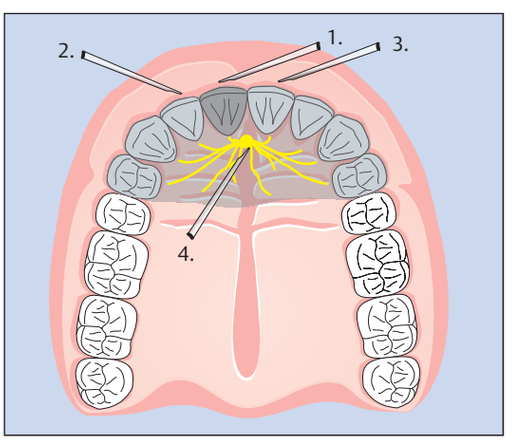


7.7 Anesthesia for endodontic surgical procedures in the maxilla

Left: Posterior segment. Buccal infiltration anesthesia and block anesthesia at the palatal foramen.

Right: Anterior segment. Buccal infiltration anesthesia and nerve block anesthesia at the nasopalatine foramen.

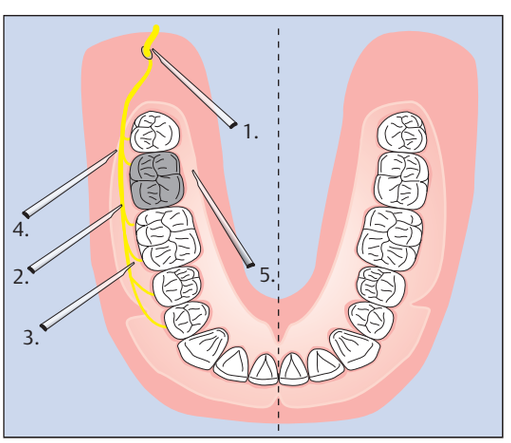


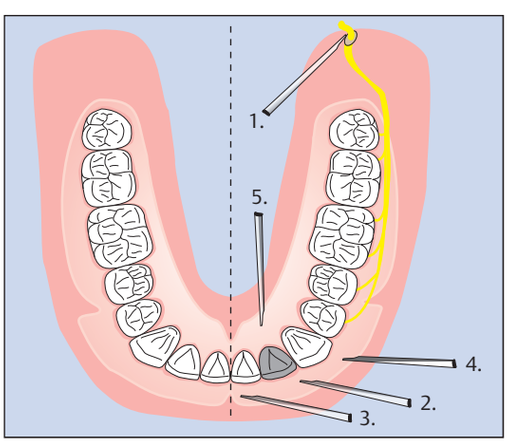


7.8 Anesthesia for endodontic surgical procedures in the mandible

Left: Posterior area. In addition to block anesthesia of the inferior alveolar nerve, one should also administer infiltration anesthesia in the buccal vestibule to reduce any mucosal discomfort and to prevent bleeding at the surgical site.

Right: Anterior segment. In most cases block anesthesia of the inferior alveolar nerve is not necessary; lingual and buccal infiltration anesthesia will usually be sufficient to block the pain.





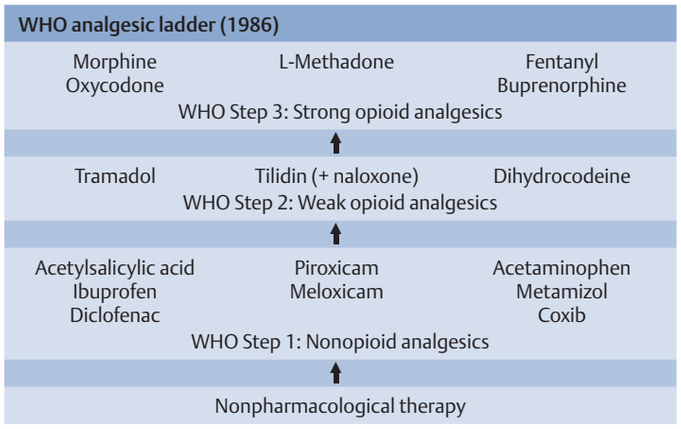
Chronic Pain and Analgesic Medications

"Pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage." (Merskey, 1979).

This definition demonstrates that pain is related not only to nociception, but also to emotions and cognitive awareness. This clinical fact must be taken into consideration in every case of acute pain, and above all in cases of chronic pain. Only with a basic understanding of this biopsychosocial situation is appropriate therapy possible.

The neuronal plasticity of the nervous system—peripherally as well as in the spinal and central planes—and the high number of patients with a psychological comorbidity may lead to a process of rethinking of traditional concepts. The following options are available to the dentist to prevent chronicity:

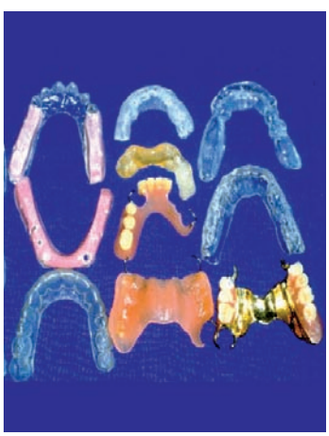
- effective reduction of acute pain during dental procedures;
- effective avoidance of repeated local irritation, such as multiple surgical procedures or recurring inflammation.



7.9 Analgesic treatment

The gold standard is the World Health Organization (WHO) analgesic ladder. Nonopioid and opioid analgesics have both peripheral as well as central nervous system effects. In general, each indicated substance should be administered primarily in an adequate dose and timespan, before any combinations are considered or changes are made.

Left: To avoid incorrect or indiscriminate self-treatment by a patient, the practitioner must provide precise analgesic information, verbally as well as in written form.

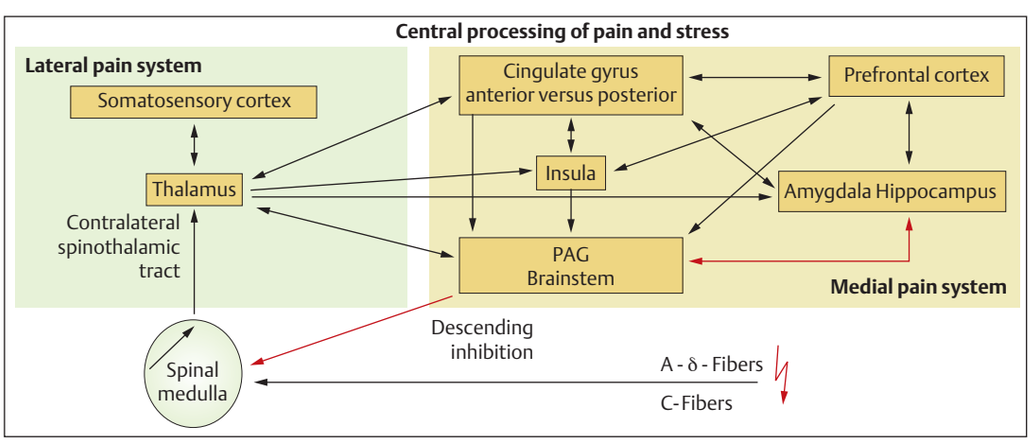


Substance	Individual dose (mg)	Dose interval (h)	Maximum daily dose (mg)	Special characteristics
Acetaminophen	500–1000	4–6	4000	Not anti-inflammtory
Acetyl salicylic acid	500–1000	4–6	4000	Risk of hemorrhage, not a long-term therapy
Ibuprofen	400–800	6–8	2400	First choice
Diclofenac	50–100	8	150	Strongest nonopioid
Metamizol	500–1000	4–6	4000	Relaxation of smooth muscles

7.10 Nonopioid therapy

For pain within the oral region, nonopioids are usually sufficient. They should be prescribed and used specifically for the particular pain. In some cases both an anti-inflammatory and an antiphlogistic effect are desirable, here cyclo-oxygenase inhibitors represent the drug of choice.

Left: Multiple splints and partial dentures used as part of monodisciplinary and mechanical therapy of chronic facial pain. This patient had depression and, after appropriate therapy, the pain symptoms subsided.



7.11 Relationship between pain and stress

Pain and stress both activate the same area of the brain. In the medial pain system the affective portions are involved, while in the lateral pain system the discriminative and cognitive functions are involved. Any irritation (pain or stress) is sufficient to activate both systems (Egle, 2003).

Antibiotics

When using antibiotics in dental treatment, two basic regimens must be differentiated: First, prophylaxis (prevention), and second, the treatment of inflammatory diseases. In order to reduce the development of resistant bacterial strains as well as the frequency of adverse effects, antibiotic therapy must be administered in appropriate doses (based on body weight and duration of effect) and over a limited period of time.

Also in immunocompromised patients, antibiotic prophylaxis should be given according to the guidelines for endocarditis prophylaxis ("single shot" prophylaxis). In this regard, the most important issue is the intraoperative drug level.

If antibiotic treatment is necessary, but no specific microorganisms have been identified, use of a calculated antibiotic regimen is recommended (e.g., drugs selected according to the *suspected* microorganism).

In the case of extensive infections or treatment resistance, appropriate tests should be carried out to determine the pathogenic microorganisms and the appropriate antibiotic preparation administered (Al Nawas et al., 2002).

7.12 Indications for endocarditis prophylaxis

The list of indications for endocarditis prophylaxis consists of conditions in which there is alteration of blood flow in the heart. Circulatory disturbances within the blood vessels can lead to accumulation of bacteria on any compromised surface and, because of inadequate local host defense response, lead to inflammation of the heart valves or the internal cardiac walls.

Low risk	Moderate risk	High risk
• Post pacemaker or defibrillator implantation • Post bypass operation • Mitral valve prolapse without mitral insufficiency • Interauricular septal defect, secundum type	• Post pacemaker or defibrillator implantation • Post bypass operation • Mitral valve prolapse without mitral insufficiency • Interauricular septal defect, secundum type	• Surgically treated heart valves • Post bacterial endocarditis • Cyanotic inherited heart defect (e.g., tetralogy of Fallot)

7.13 Endocarditis prophylaxis

Endocarditis prophylaxis is the gold standard and should be instituted for every oral procedure leading to hemorrhage—in particular, periodontal injury. On the other hand, the use of such prophylaxis is controversial because of the possible adverse effects of the antibiotics (primarily allergic reactions).

Initial situation	Antibiotic	Dosage	Route of administration	
No special considerations (standard prophylaxis)	Amoxicillin	2.0 g	Oral	1 h before procedure
Patients who cannot take oral medications or who are already receiving intravenous medications	Amoxicillin	2.0 g	Intravenous	30 min before procedure
Penicillin allergy	Clindamycin	600 mg	Oral	1 h before procedure
Penicillin allergy in patients who cannot take oral medication or are already being treated intravenously	Clindamycin	600 mg	Intravenous	30 min before procedure

7.14 Substances and preparations for use in dentistry/endodontology

In clinical studies penicillin V, amoxicillin plus clavulanic acid, as well as clindamycin and the newer macrolides have proved effective. According to the guidelines of the Paul-Ehrlich Society, penicillin V is no longer the drug of choice, but instead an aminopenicillin + β-lactamase inhibitor is preferred (Vogel et al., 2002).

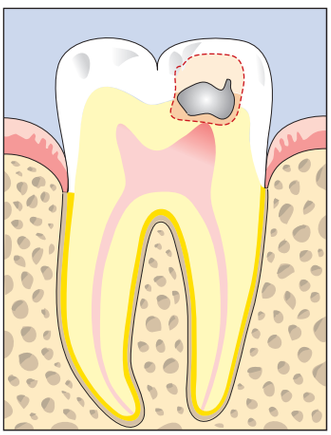
Note: The preparations listed are examples only; this is not a complete list.

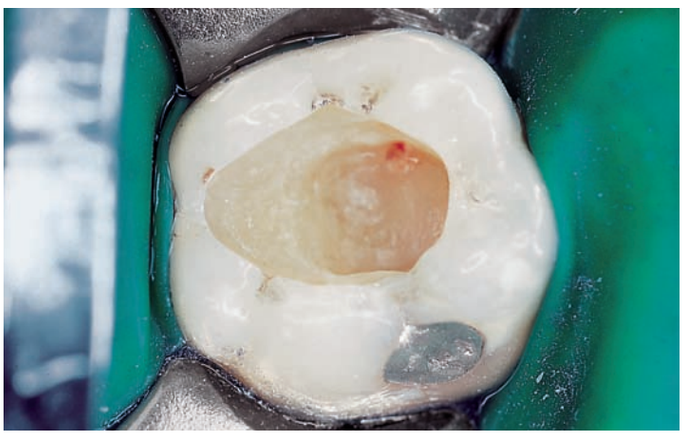
Substance	Generic name	Trade name	Dosage
Penicillin V	Phenoxymethylpenicillin	Isocillin Megacillin	3 × 1.5 million I U
	Propicillin	Baycillin	3 × 1 million I U
Aminopenicillin	Amoxicillin	Amoxypen	3 × 1 g (750 g)
Aminopenicillin + β-lactamase inhibitor	Amoxicillin + clavulanate	Augmentin	3 × 625 mg, 2 × 825/125 mg
Clindamycin	Clindamycin	Sobelin	3 × 300 mg
Cephalosporin	Cefadroxil	Gruncef	2 × 1 g
Tetracycline	Doxycycline	Azudoxat	2 × 100 mg
Macrolide	Roxithromycin	Rulid	1 × 300 mg
Nitroimidazole	Metronidazole	Clont	3 × 400 mg

8 Emergency Endodontics

The dentist in general practice is most often confronted with pain of endodontic origin. Carious lesions (also secondary caries) are the primary culprit in 88% of cases, followed by cusp fracture, hypersensitive cervical areas, and traumatic occlusion. If the patient can identify the responsible tooth, or a radiograph reveals apical pathology, or there are additional clinical symptoms (e.g., sensitivity to percussion or a fistula) that provide clues about the affected tooth and the overall pathophysiologic situation, a treatment decision should be made quickly. If the patient reports radiating pain not directly related to a specific tooth, symptomatic treatment should be initiated.

Clinical studies have reported varying rates of success following direct pulp capping as an emergency treatment measure, ranging from 97.8% after 1.5 years to 61.4% 5 years later. In one clinical study, the success rate of 37% after 5 years dropped to only 13% after 10 years. Similar clinical studies following immediate extirpation of the exposed vital pulp found significantly higher success rates. For example, Rocke reported a 5-year success rate of 93% for all endodontically treated teeth, and a 10-year success rate of 81%. An exception to these excellent results were immature teeth with exposed pulps whose root growth was not yet complete.

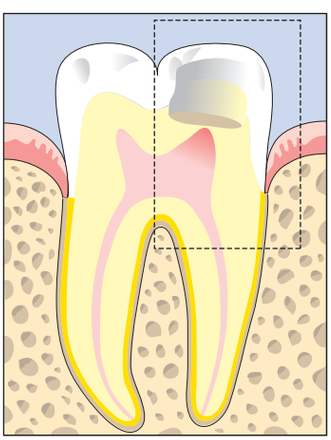


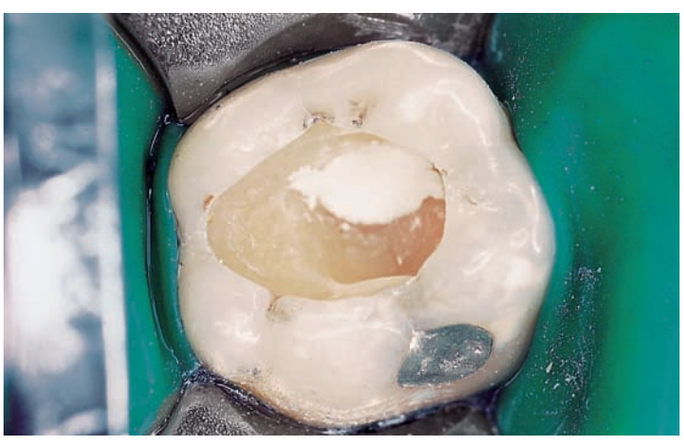


8.1 Step one

Hemostasis should be attempted immediately following a pulp chamber exposure.

Left: The caries lesion has not yet involved the pulp horn.

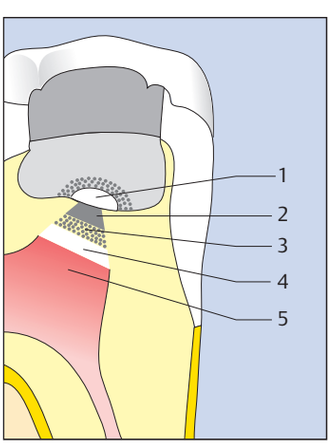


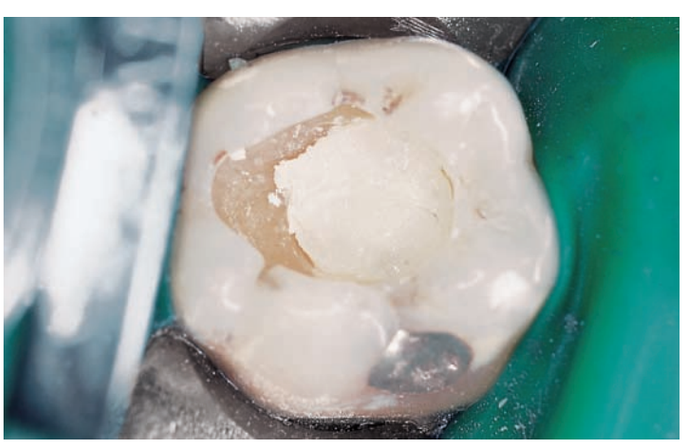


8.2 Step two

Apply a water-based calcium hydroxide paste as a thin layer and press it lightly with a sterile cotton pellet. Wait a few minutes to determine whether any blood seepage occurs; if this is the case, the pulp capping material should be washed out and reapplied after bleeding has been completely stopped. An excavator is used to remove any excess material so that only the root canal orifice is covered.

Left: Such pulp capping procedures may only be performed if the dentin is caries-free.





8.3 Step three

The calcium hydroxide capping material is covered with zinc oxide eugenol cement, followed by glass ionomer cement, and a definitive restoration using composite resin.

Left: Against the regenerating, inflamed pulpal tissue with temporary damage is a zone of reparative dentin (2), diffuse mineralization (3) and osteoidlike dentin (4) and the zone of necrosis (5). The calcium hydroxide paste (1) is covered with zinc oxide eugenol, and the cavity is then filled with glass ionomer cement and a composite restoration.

Pulpal Diagnosis

Before attempting any management of pain of dental origin, the clinician must establish whether the patient has irreversible or reversible pulpitis or necrosis with or without apical involvement.

The transition into irreversible pulpitis is gradual, making precise diagnosis very difficult. In the first instance, the pulp chamber is not directly violated, but there may be a fractured restoration, exposed dentin, or an inadequate restoration. Pain can be elicited by stimuli such as cold, sweet, and sour and is of short duration.

The standard sensitivity test is positive, but there is no pain on percussion. A radiograph usually reveals deep caries or an old restoration with secondary caries; there are generally no radiographic signs of periapical involvement. Pulpal diagnosis has as its goal the maintenance of tooth vitality while simultaneously eliminating pain. This will usually involve complete removal of all old restorations and caries; in no case should residual caries be left untreated. Only by these measures is it possible to eliminate the possibility of additional pulpal irritation. When the patient has been pain-free for 48 hours, the tooth can be restored. If pain persists or increases in intensity, it indicates that irreversible pulpitis is present. In such cases, the root canal must be appropriately instrumented endodontically and later definitively restored.

8.4 Diagnosis

Approximately 4 months after placement of a composite restoration, this patient presented with pain in the maxillary anterior region. The restorations were removed using a dental explorer; carious dentin that had not been completely removed is clearly visible. The caries was fully excavated, and the cavities were lined with zinc oxide eugenol cement with a low proportion of eugenol.

Right: The teeth were not sensitive to percussion, but in the radiograph the lateral incisor shows a slight widening of the periodontal ligament space.

8.5 Treatment

The primary and secondary caries beneath the inadequate restorations were removed as far as possible without exposing the pulp. Subsequently the cavities were temporarily restored for 24–48 hours, using a temporary filling material.

Right: On the next day, a definitive swelling in the right infraorbital area was evidence of the failure to make the expected pulpal diagnosis. Maintenance of tooth vitality was no longer possible and a soft-tissue incision was made. The following day the patient was free of symptoms.

8.6 Conclusion of treatment

After another 2 days, the root canals were instrumented in all three teeth and a calcium hydroxide dressing was applied loosely into the canals.

Right: Three weeks later, the patient was symptom-free and definitive root canal fillings were placed.

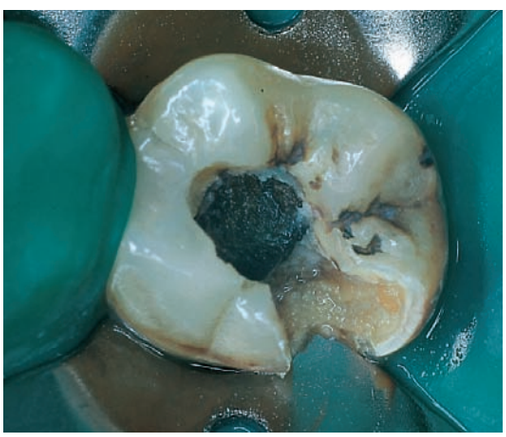
Devitalization of the Pulpal Tissues

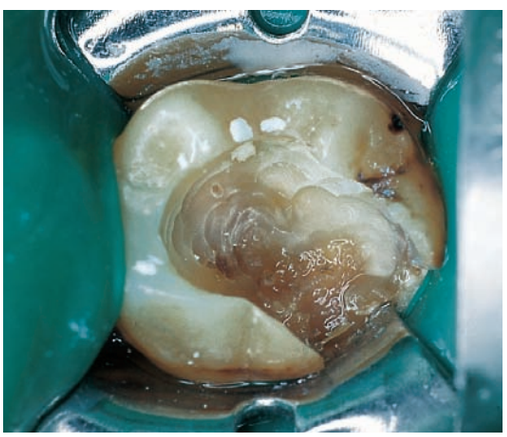
An important component of all devitalization pastes is paraformaldehyde. It leads to coagulation and denaturation of cell wall proteins, which, finally, results in the arrest of all vital cell functions. The tissue becomes "fixed," and this state of fixation is irreversible.

Animal experiments have demonstrated cellular toxicity, mutagenesis, carcinogenesis, and genotoxic changes. Using radioactively labeled paraformaldehyde, 14 days following pulpectomy, accumulation of metabolites in the liver has been observed. Systemic dissemination has also been observed in blood plasma, as well as in the lungs and kidneys.

With root canal fillings that are inadequately sealed, the result may be sequestrum formation in the adjacent bone, ultimately leading to tooth loss. Even with optimally sealed proximal restorations it is not always possible to inhibit the penetration of formaldehyde into adjacent bone, where damage can occur.

At the time of writing, there are no indications for devitalization of the pulpal tissues as "emergency" therapy. The numerous adverse effects far outweigh the potential beneficial effects.

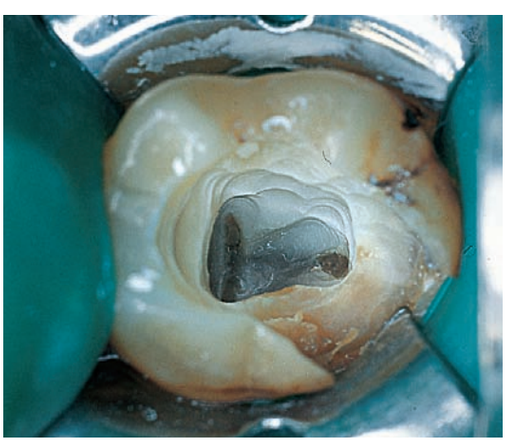


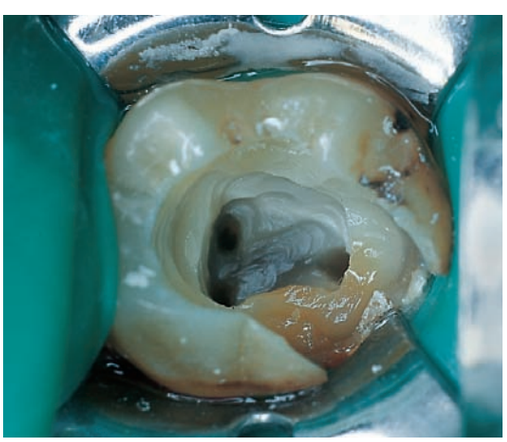


8.7 Diagnosis

Left: Ten days after an emergency visit, this patient presented to her dentist's office with continuing mild discomfort. Tooth 37 was isolated using a rubber dam. Following removal of the temporary restoration, a dark-gray devitalization paste was visible near the incompletely exposed root canals.

Right: The devitalization paste and residual carious dentin have been completely removed.

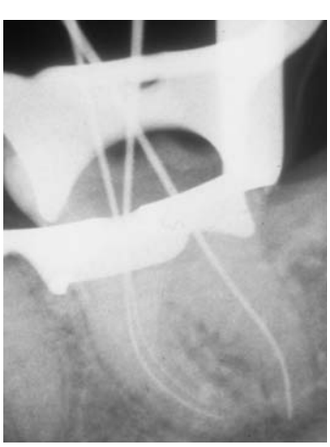




8.8 Treatment

Left: Following preparation of the access cavity and the removal of the fixed and non-bleeding coronal pulp tissue, the canal orifices became visible.

Right: The root canals were instrumented using the crown-down technique and thoroughly irrigated with sodium hypochlorite solution and EDTA.



8.9 Conclusion of treatment

Left: Following precise determination of root canal length, all the root canals were completely instrumented and a temporary dressing applied to each canal.

Middle: Following a symptom-free period, definitive root canal fillings were placed and the coronal aspect was definitively restored.

Right: A bony sequestrum, approximately 5 mm in size, was removed from the interdental area.

Emergency Involving a Vital Pulp: Amputation of the Coronal Pulp

Among emergency treatments of irreversible pulpitis, immediate endodontic treatment with extirpation and temporary filling provides the highest rate of success, with 99% freedom from pain. However, in the case of molars, this treatment is not possible as an unplanned treatment modality.

The goal in every case should be immediate relief of pain. This is also possible in multirooted teeth, without the use of toxic medicaments, which reserves the option of subsequent (planned) definitive root canal treatment. The elimination of pain by means of amputation of the coronal pulp at the level of the root canal orifices is the treatment of choice (success rate 96%).

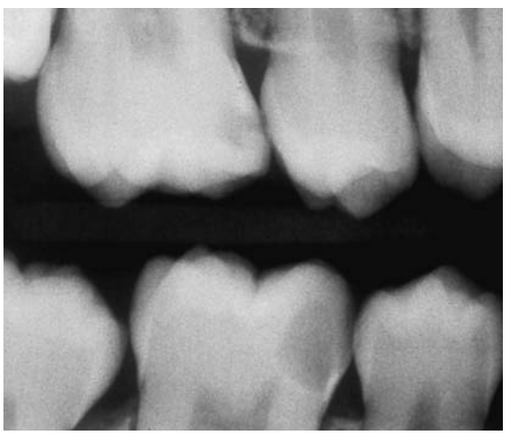
Following local anesthesia and application of a rubber dam, a high-speed handpiece is used to completely remove the carious tooth substance. Subsequently the coronal pulp is extirpated. Using a sterile, moist cotton pellet, the bleeding is stopped. A eugenol-soaked cotton pellet is placed in the pulp chamber and a temporary restoration carried out.

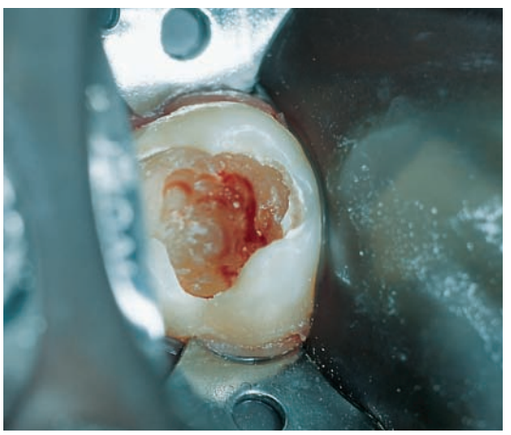
In one clinical study, 78% of patients who underwent amputation of the coronal pulp were free of pain. One day later *all* patients were free of pain although 8/70 patients continued to experience minor discomfort. Thirty days later, all of the patients in the study were free of pain or discomfort.

8.10 Diagnosis

Left: A bitewing radiograph of the left posterior segment in a 13-year-old girl showing a deep caries lesion on the proximal surface of tooth 36.

Right: During caries excavation, a large exposure of the pulpal tissues has occurred. As an interim solution, under local anesthesia, the a large access cavity has been prepared, and the coronal pulp excavated using a stainless-steel bur.



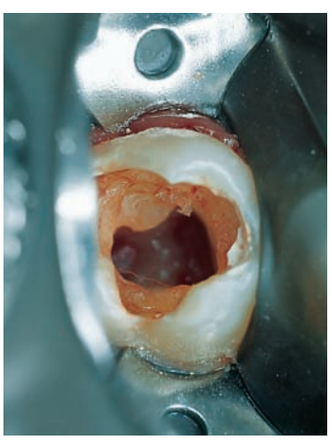


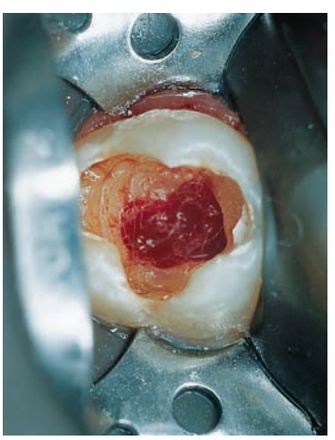
8.11 Treatment

Left: The coronal pulp has been removed and bleeding has been stopped by using a sterile cotton pellet, or a pellet soaked in ferrous sulfate.

Middle: Subsequently a cotton pellet soaked in eugenol or sterile saline solution is forced into the cavity and the cavity is temporarily restored.

Right: If the growth of the root is well advanced, the pulpotomy can represent a short-term solution, awaiting completion of root formation in this young individual.

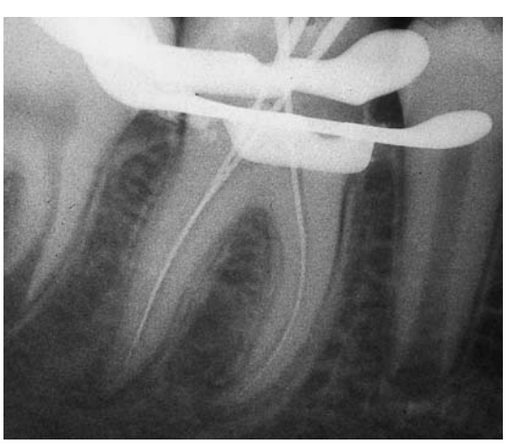




8.12 Completion of treatment

Left: At a subsequent appointment, all the root canals were completely instrumented and irrigated.

Right: As the patient was symptom-free, the root canals were definitively filled at the same sitting.



Pulpotomy is indicated in a symptom-free permanent tooth with incomplete root growth, a large pulp exposure, and with inflammation or inflammation limited to the coronal pulp. Definitive endodontic treatment should always be carried out within 48 hours after pulp exposure (e.g., trauma). Pulpal amputation is considered as an interim measure. Under local anesthesia, the coronal pulp is removed using a diamond bur, the pulp chamber is irrigated with saline solution and a sterile cotton pellet is placed to stop any bleeding from the root canal orifices. The presence of a blood clot between the pulp capping material and the residual radicular pulp tissue in the canal delays or impedes the formation of a hard tissue bridge.

Following the formation of a hard tissue bridge, as early as 4 months after the initial procedure, deposits of reparative dentin lead to virtual obliteration of the root canals. Following completion of root growth, in spite of freedom from symptoms, complete endodontic treatment with extirpation of the residual radicular pulp should be carried out.

In summary, the goal of pulpotomy is temporary maintenance of vital root canal pulp to allow completion of root growth with formation of an apical constriction.

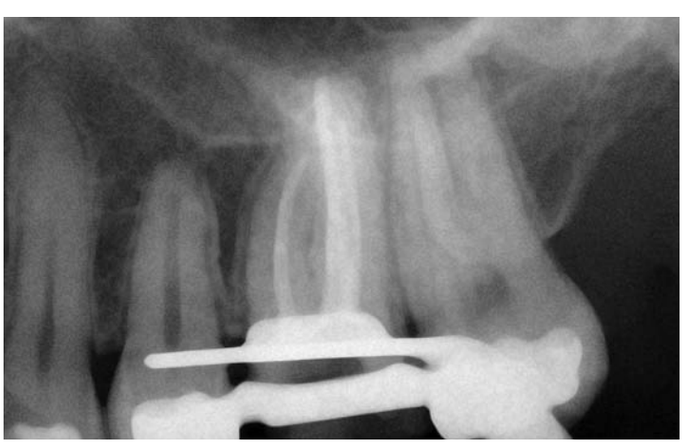
8.13 Diagnosis

Subsequent to a previous partial pulpal amputation, granulation tissue has grown and developed into open pulpitis (pulpitis aperta).

8.14 Treatment

Left: Under local anesthesia the entire coronal pulp was removed and bleeding completely stopped.

Right: The radiograph shows the results of the pulpal amputation; there is no further progression of the inflammatory process into the periapical region.



8.15 Treatment conclusion

At a later date, root canal treatment was completed in a single sitting.

Emergency Involving a Necrotic Pulp

The goal of emergency therapy in cases of pulpal tissue necrosis is to eliminate pain without having to completely instrument the root canal. The diagnosis is usually helped by the presence of initial periapical radiolucencies in the radiograph.

In contrast to cases of irreversible pulpitis, necrotic pulp tissue must be completely extirpated from the root canals. The best chance for successful treatment involves complete instrumentation of the root canal at the initial appointment, which is quite possible with single-rooted teeth. However, this can be considerably more difficult in multirooted posterior teeth, due to the complex root canal anatomy. In such cases, the best result will be achieved if the largest and easiest-to-instrument canals can be completely instrumented.

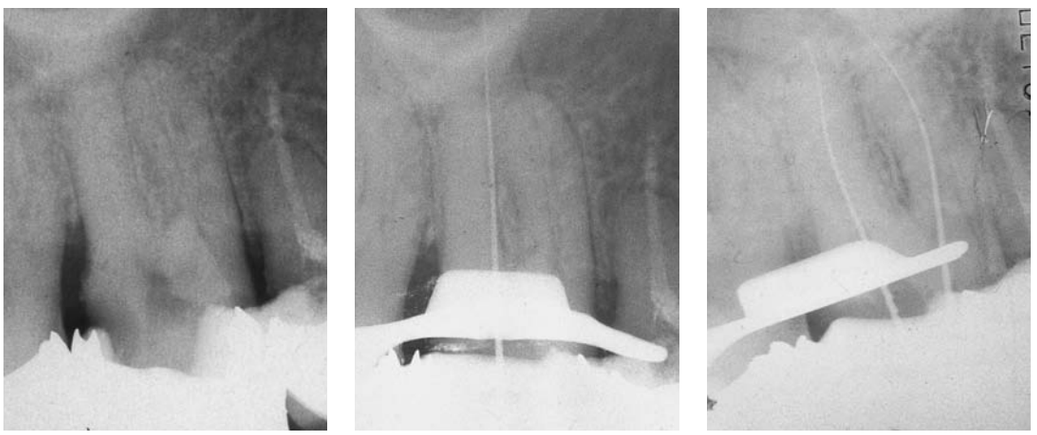
The largest colonies of bacteria are generally found in the necrotic coronal pulp, extending into the radicular pulp. The goal of emergency therapy is to completely remove the inflamed tissues. The instrumentation should be performed using the crown-down technique, that is, proceeding from the coronal to the apical end. Important in this regard is adequate coronal access. The instrumented root canals are then thoroughly irrigated and the access cavity completely sealed.

8.16 Emergency treatment

Left: An additional option in emergency treatment of multirooted teeth is the complete instrumentation of only the largest root canal. The other narrow and curved canals are not instrumented even if they contain necrotic material.

Middle: Following cavity preparation and complete removal of the coronal pulp, only the palatal canal is instrumented and filled with calcium hydroxide.

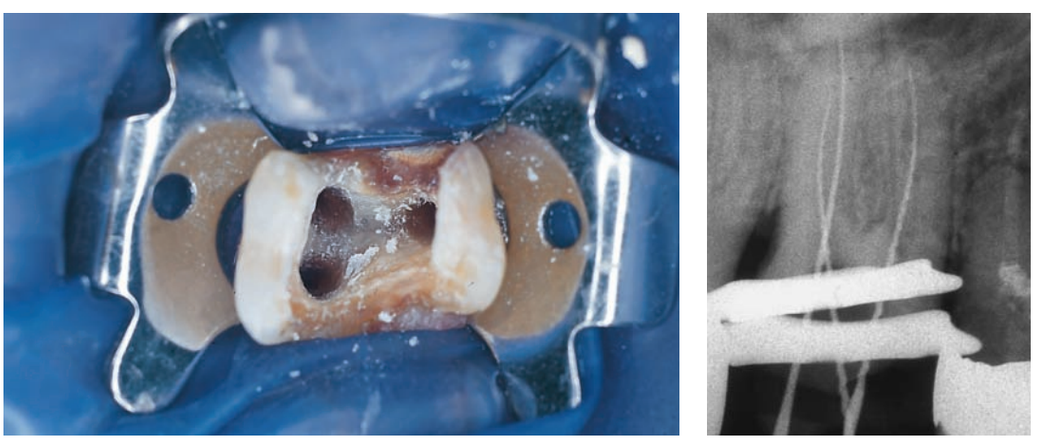
Right: Five days later, the remaining root canals are also completely instrumented.



8.17 Root canal treatment

The planned root canal treatment is carried out at a second sitting.

Right: Following coronal widening, the working length is determined radiographically and all root canals are instrumented.

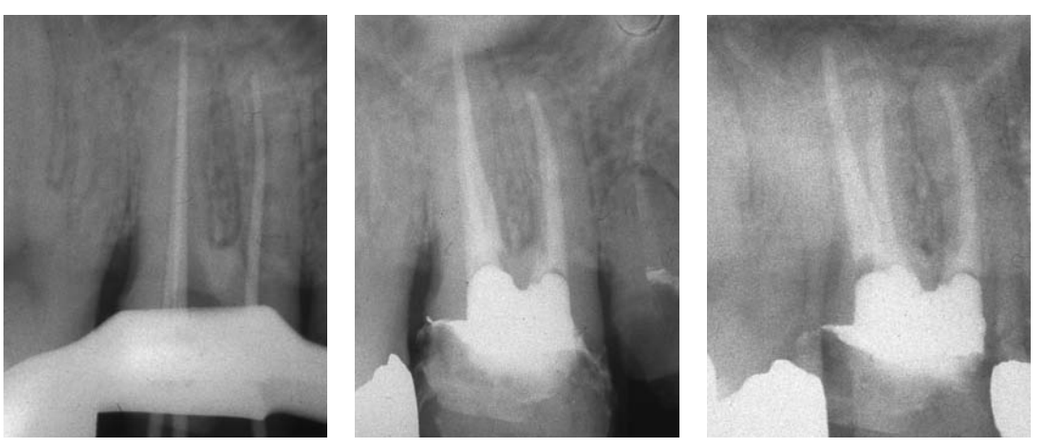


8.18 Root canal filling

Left: If the patient is symptom-free, definitive root canal filling can be carried out at the same sitting. However, the dentist may also elect to place an interim calcium hydroxide dressing. The gutta-percha points are placed with regard to the radiographic assessment of the master point.

Middle: Radiograph of the root canal fillings.

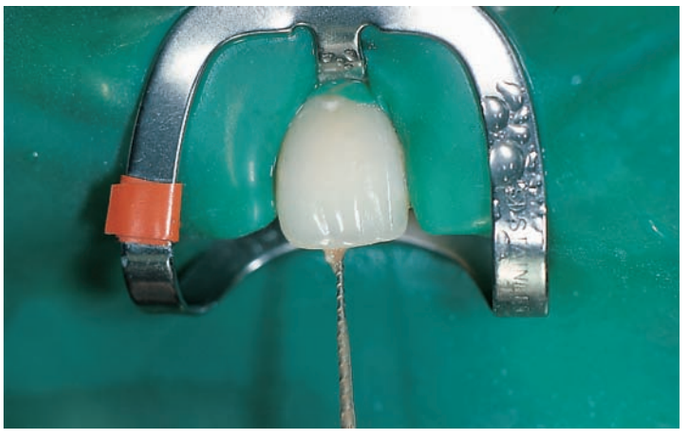
Right: This distal eccentric radiograph revealing a pathology-free periapical region.



If there is persistence of the bacterial infection within the root canal, a periapical abscess may develop. Acute apical periodontitis is characterized clinically by sensitivity to percussion as well as pain on axial loading of the tooth. A periapical abscess may be acute or it may exist as an encapsulated chronic abscess. In its initial stages the abscess is not visible in a radiograph. However, the massive inflammatory cell infiltration in the periapical region, and the subsequent osteoclastic activity lead to visible osseous destruction within 3–4 weeks.

If a chronic apical periodontitis becomes secondarily infected with bacteria, it is referred to as a "phoenix abscess," that is, there is acute exacerbation of the chronic process. This is evidenced on the radiograph as a periapical radiolucency and clinically as marked sensitivity to percussion, apparent tooth "lengthening," and severe pain.

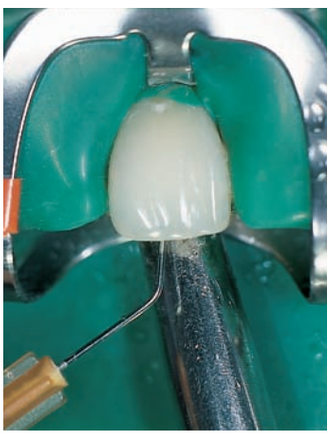
Histologically, in teeth with pain, swelling, or fistula formation, the periapical lesions do not have characteristics different from those associated with symptom-free teeth. However, in teeth with spontaneous pain or sensitivity to percussion, there is much greater bacterial infiltration of the root canals compared with teeth with no clinical symptoms.

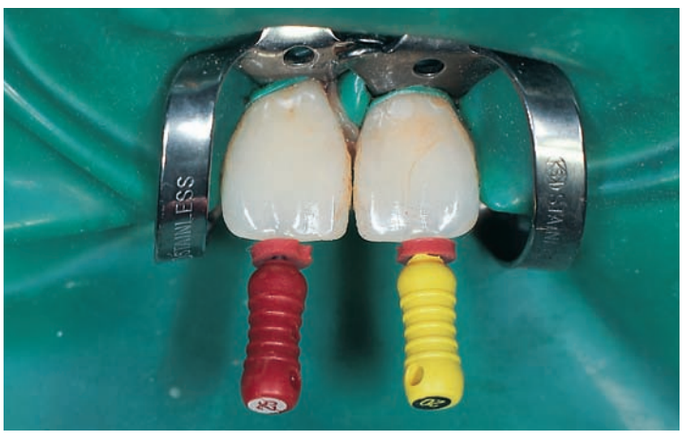


8.19 Diagnosis

Left: The radiograph shows periapical radiolucencies in relation to both maxillary central incisors.

Right: Following cavity preparation and complete removal of the coronal pulps, the root canals were widened coronally and apically to file size 15.

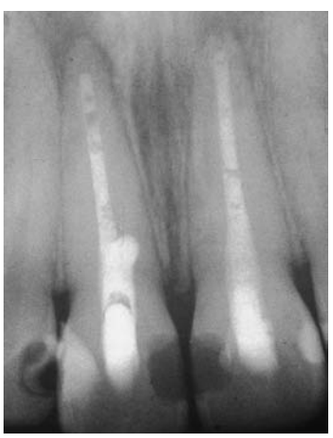




8.20 Root canal treatment

Left: The instrumented root canals were thoroughly irrigated with sodium hypochlorite and EDTA, or citric acid.

Right: Definitive endodontic therapy at the second sitting.



8.21 Instrumentation and filling

Left: After coronal widening the working length is determined radiographically and the canals are instrumented.

Middle: In the absence of clinical symptoms, a calcium-hydroxide dressing is inserted into the canals.

Right: At the third sitting, the definitive root canal fillings are placed; after only 6 months one notices a marked resolution of the periapical radiolucencies seen at baseline.

Emergency Involving Acute Apical Periodontitis

The diagnosis of acute periapical periodontitis should be based on clinical findings and interpretation of the radiograph. The involved tooth is sensitive to pressure and percussion and usually somewhat mobile or slightly raised in its socket. In many cases, swelling of the adjacent soft tissue can be observed, although with an acute periapical inflammation, fistula formation is unlikely. However, a pre-existing fistula may close during this phase of the pathologic process, resulting in acute symptoms. The swelling may be fluctuant, localized or diffuse and may be intra- and/or extraoral.

The goal of treatment is to achieve efficient drainage of pus, and subsequent treatment stages are similar to the treatment of any necrotic pulp.

In a patient with a localized swelling, the affected tooth should be drilled to drain by way of the root canal. In most cases the pulp chamber is exposed coronally and the majority of infected tissue is removed. Thereafter, using a size 15 Hedström file the root canal is instrumented down to the apex and the canal widened slightly.

8.22 Palatal swelling

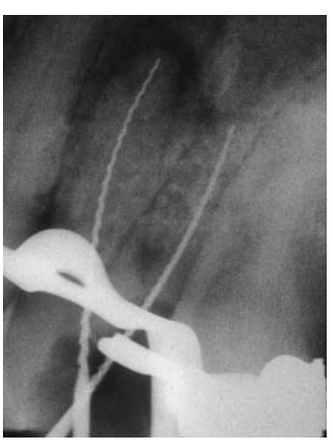
A 2–3-cm fluctuant swelling on the palate, extending posteriorly from the first premolar.

Right: Following access cavity preparation and removal of the coronal pulp, there was spontaneous discharge of pus via the root canal, which was left open for about 20 minutes. Then the root canals were instrumented using the crown-down technique.

8.23 Instrumentation

At this initial sitting the infected pulpal tissue was completely removed and the root canals were irrigated and then filled loosely with a calcium-hydroxide dressing.

Right: Radiograph showing a periapical radiolucency as well as endodontic files in the two root canals for canal length estimation.



8.24 Completion of treatment

Three weeks later the palatal swelling is no longer discernible; at this visit, further instrumentation can be carried out, including changing of the interim dressings.

Right: At the third sitting the root canals can be definitively filled, if no exudation via the canals is discernible.

If the patient presents with a relatively large and fluctuant swelling that does not decrease in size after the root canal has been opened, a soft-tissue incision may be indicated (see also below). Prior to this, however, the canal must be instrumented, irrigated, and loosely filled with chlorhexidine gel, then closed coronally.

If there is sufficient pus discharge via the root canal, it should be left open for only 20 minutes—under the rubber dam—and enlarged one to two times its size, followed by application of chlorhexidine gel and sealing for 3–5 days. Only at the second endodontic sitting is the root canal completely instrumented.

If the soft-tissue swelling is diffuse, there is no indication for an external incision. The patient should be prescribed a regimen of antibiotic therapy and the root canal completely instrumented. The canal is irrigated alternately with sodium hypochlorite and 0.2% chlorhexidine and an EDTA-containing solution. Then, after complete drying of the canal, a mixture of calcium hydroxide and chlorhexidine is inserted loosely into it, and the patient is given an appointment 24 hours later for a follow-up examination.

8.25 Diagnosis

Left: Tooth 22 fractured at the level of the gingival margin. The history revealed that the tooth had been in this condition for about 1 year; only the increasing pain led this patient to visit the dentist.

Middle: The palatal swelling was incised as an emergency measure.

Right: The radiograph shows a periapical radiolucency as well as signs of previous root canal treatment.

8.26 Treatment

The 41-year-old woman had suffered for 1 week with increasing discomfort as well as initial swelling in the infraorbital region.

Left: After application of the rubber dam, and using aseptic procedures, the carious dentin was excavated and the root canal orifice revealed.

8.27 Treatment conclusion

Left: Following instrumentation during the initial sitting the tooth was prepared for a temporary post build-up restoration.

Middle: A calcium-hydroxide mixture was inserted within the root canal as a temporary dressing.

Right: The patient was free of pain, and at the next sitting, 3 months later, the definitive root canal filling was carried out, as well as the definitive restorative treatment of the tooth.

Pain Following Canal Instrumentation

The incidence of postoperative pain varies between 1.4% and 45% among published studies. In most cases it requires an additional visit to the endodontist/dentist. The patient will undoubtedly experience pain following incomplete debridement (e.g., leaving behind remnants of necrotic tissues and pulp tissue with bacterial infiltration). Bacteria and their by-products (endotoxins) can release pain mediators.

Medicated dressings may exert toxic effects directly, or indirectly, and cause postoperative complications by suppressing host-specific defense mechanisms. Another cause is apical extrusion of necrotic-tissue remnants during canal instrumentation. Despite precise root canal length estimation, the rasping movement of the root canal instrument can cause extrusion of debris including microorganisms and necrotic-tissue remnants as well as the irrigating solution. This leads to periapical inflammation and a foreign-body reaction.

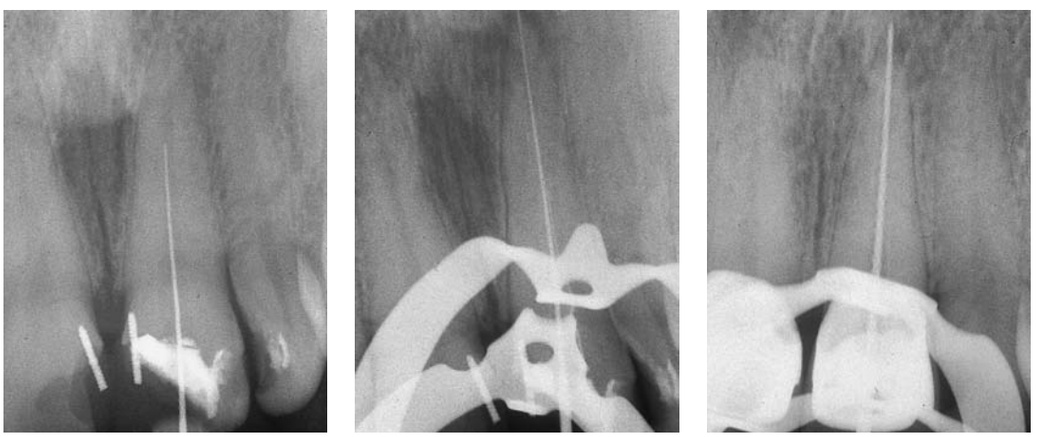
Undoubtedly, the best method for prevention of postoperative pain is effective emergency treatment with complete cleansing of the root canal using the crown-down technique to achieve apical patency.

8.28 Initial therapy

Left: At the initial, emergency, treatment sitting, the canal was incompletely instrumented and a temporary dressing placed.

Middle: Seven days later the tooth was again opened, and after length determination the canal was slightly over-instrumented.

Right: Subsequently the canal was completely instrumented and a calcium-hydroxide dressing was placed.



8.29 Incision

Only 24 hours later the patient returned with a noticeable swelling resulting from extrusion of necrotic and infiltrated tissues.

Right: An incision was made to release pus, and this resulted in immediate improvement of the pain.

8.30 Conclusion of treatment

Left: Five days after the acute symptoms had subsided, the root canal was again instrumented and then filled 2 weeks later.

Middle: At the same appointment, the tooth was restored using a composite build-up.

Right: Follow-up clinical image shows only slight scar formation at the soft-tissue incision site.

Instruments and Materials

B

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9 Conventional Instruments and Advances in Design

All endodontic hand instruments are based on three basic forms: K drills (= K reamer), K files, and Hedström (H) files. Initially fabricated from carbon steel, since the 1960s all endodontic hand instruments have been made from stainless steel, and are therefore less likely to corrode with frequent sterilization. Smaller K-type files are fabricated by twisting a file blank with a square (four-edged) cross section, whereas file sizes >30 are produced by twisting a triangular blank (see Figs. 9.1, 9.2).

The square cross section is more stable and stiff, with less chip space between the threads (36%) so a smaller amount of dentin is cut away from the canal walls. The triangular cross section is more flexible, with wider chip spaces between the threads (60%), but is also more susceptible to fracture.

With cutting angles of <45°, use of a rotary filing technique is ideal. This is true for K reamers (with an angle of at least ~20°) and K files (~40°).

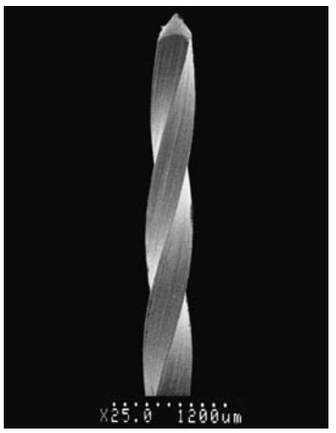
Hedström files are milled from round steel stock. They exhibit sharp edges with an angle of ~60° and are therefore highly efficient for root canal instrumentation. They are significantly more efficient than K files, which are often recommended for pure filing, although K files are more effective with a rotatory motion (Tepel et al., 1995).

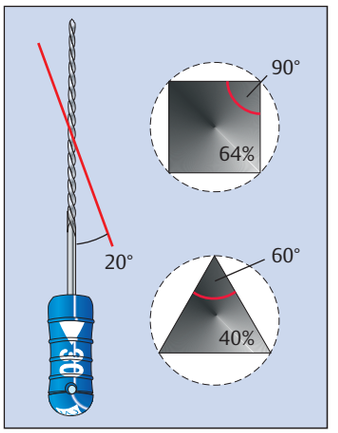
9.1 K files

Left: The K reamer or K drill (from left: VDW, Kerr, Maillefer) is one of the most basic types of endodontic instruments.

Middle: Scanning electron photomicrograph (SEM; ×25 magnification) showing the number and geometry of the flutes in a reamer (0.5–1 twists/mm).

Right: While the triangle is the symbol for reamers, the square profile is used for smaller sizes (chip space of 36%) and the triangular profile for larger sizes (chip space 60%).



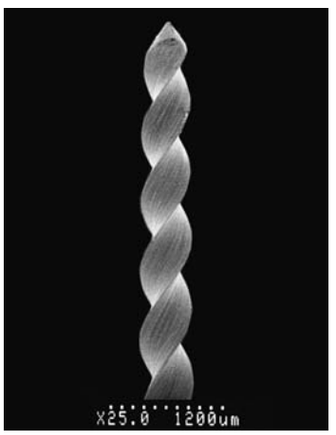


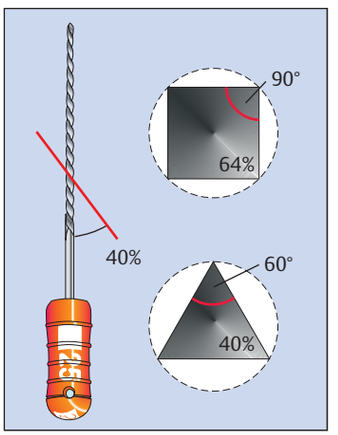
9.2 K files

Left: In 1915, Kerr Manufacturing Corporation received the patent for all subsequent K-type instruments (e.g., the K files).

Middle: SEM (×25 magnification) showing the larger number of flutes (1.5–2.5 twists/mm) in comparison with K reamers.

Right: Smaller K files also have a square cross section and larger ones a triangular cross section. The symbol is, however, the square. The angle of the cutting edge is 25–40°, about twice as large as that of reamers.



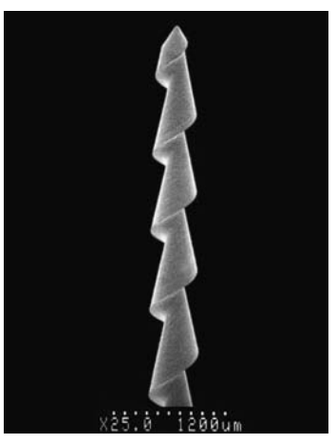


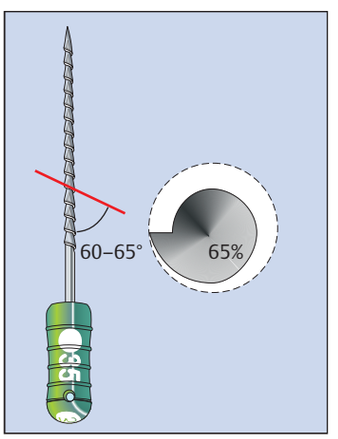
9.3 H files (Hedström files)

Left: In contrast with the K-types, Hedström are milled from round steel stock.

Middle: SEM (×25 magnification) clearly depicting the geometry with a helicoid cutting edge.

Right: The cross section of an H file is round with a milled spiral, permitting a chip space of 35%. The symbol is a circle. The cutting edge angle is 60–65°.



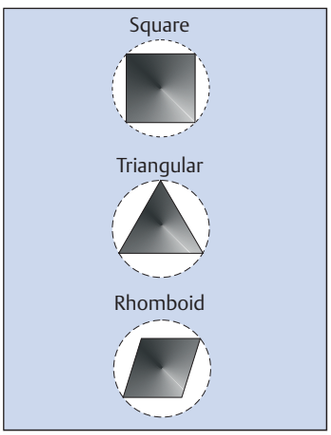


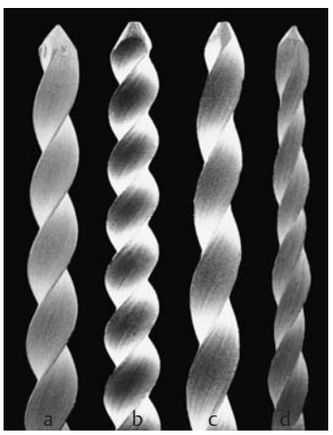
Further Developments

In order to overcome the disadvantages of conventional hand instruments, hybrid instruments were developed in an attempt to incorporate the advantages of K-type files with the aggressive cutting power of the H-type files. The combination provided increased flexibility by altering the file cross section (rhomboid: K-Flex; triangular: for greater than size 15 [Flexofile, Flexoreamer]; and special steels: Flexicut).

A new era began with the Flex-R-File (Roane et al., 1985), which was developed after it was recognized that sharp edges at the tip of a file could cause problems during instrumentation; so the edges were rounded off based on the principle of the noncutting tip. It was also possible to incorporate this principle into the design of the Flexofile and reamers. In addition, although the Flex-R-File is a modified K-type file with a triangular cross section, it is produced by milling round steel stock, similar to H files. Similarly, Unifiles and S files are manufactured as double helices. With the incorporation of a shorter working section (Canal-Master-U, Flexogates, Heliapical), the aim was to minimize shape changes.

To date, ISO numbers have increased linearly, in contrast to the erratic increase in the diameter of the files,, and intermediate sizes have been developed. A constant increase of 29% (profile 29) remains under discussion (Schilder and Tee, 1994).



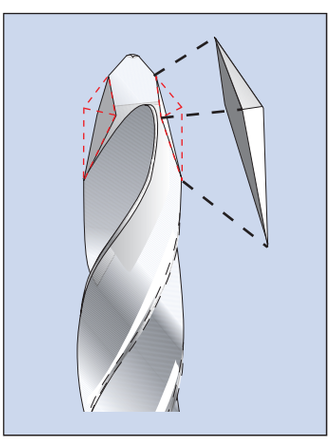


9.4 Flexible instruments

Left: Most recent instruments, even the smaller diameter ones, have a triangular profile (a–c). The rhomboid shape (d) is also more flexible, but has only two cutting edges.

Middle: The number of cutting edges in the Flexofile (b) is significantly higher. In the K-Flex (d) wider segments alternate with narrower segments (rhomboid form).

Right: (a) Flexicut (VDW), (b) Flexofile (Maillefer), (c) Flexoreamer (Maillefer), (d) K-Flex (Kerr).



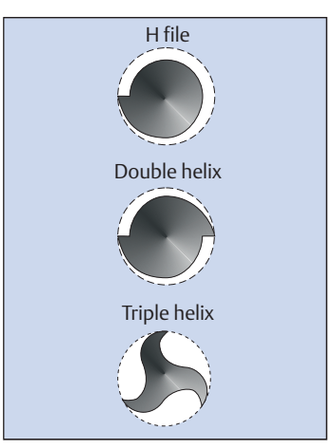
9.5 Blunt tip

The Flex-R-file designed by Roane (1985) was the first to have a noncutting ("Batt") tip, which made it possible to avoid step creation even in curved canals.

Left: Principle of the Flex-R-file → removal of the sharp section of the instrument tip (blunt form).

Middle: This SEM photomicrograph clearly shows the tip geometry (×200 magnification).

Right: Maillefer also offers intermediate file sizes 12–37 with blunt tips (Golden Mediums).



9.6 Additional modifications

Some manufacturers have significantly reduced the working area of the file, so that a shorter cutting section is attached to a longer shaft of rounded stainless steel.

Left: The simple helicoid cross section of the Hedström file was doubled in the S file (Sendoline) and increased threefold in the Helifile (MICRO-MEGA).

Middle: Flexogate (Maillefer) with a 2-mm long working section.

Right: Heliapical (MICRO-MEGA) with a 5-mm long working section.

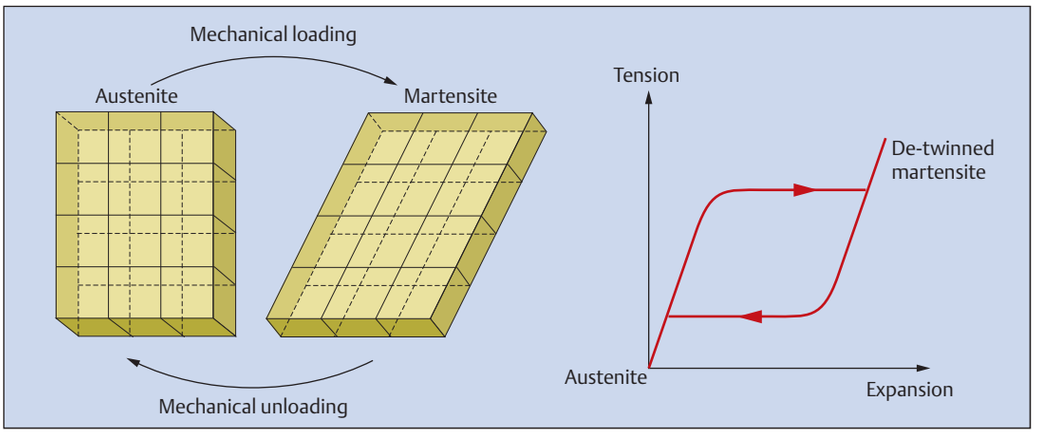
10 Nickel-titanium: Materials Science

About 20 years ago, the first fabrication of endodontic instruments from nickel-titanium alloys (NiTi) set in motion a development that fundamentally changed root canal instrumentation forever (Walia et al., 1988). The 55-Nitinol (approximately 55% Ni and 45% Ti) still contained traces of iron (Fe) and cobalt (Co). It was characterized by *pseudoelasticity*. After loading and unloading, it returns to its initial shape ("memory effect"); however, in the phase change, NiTi exhibits hysteresis with dissipation in contrast with the usual elasticity.

There are other "memory" alloys that undergo a diffusionless phase change (e.g., CuZnAl, AuCd). This phenomenon also occurs during the hardening process of steel: On rapid cooling from a high temperature, carbon (C) has insufficient time to undergo diffusion and atomic rearrangement of the cubic, surface-centered austenitic form, and instead it assumes a body-centered tetragonal structure with volume change. This diffusionless change is referred to as "martensitic change," named after its discoverer, Adolf Martens (Director of the Materials Test Center, Berlin, 1850–1914).

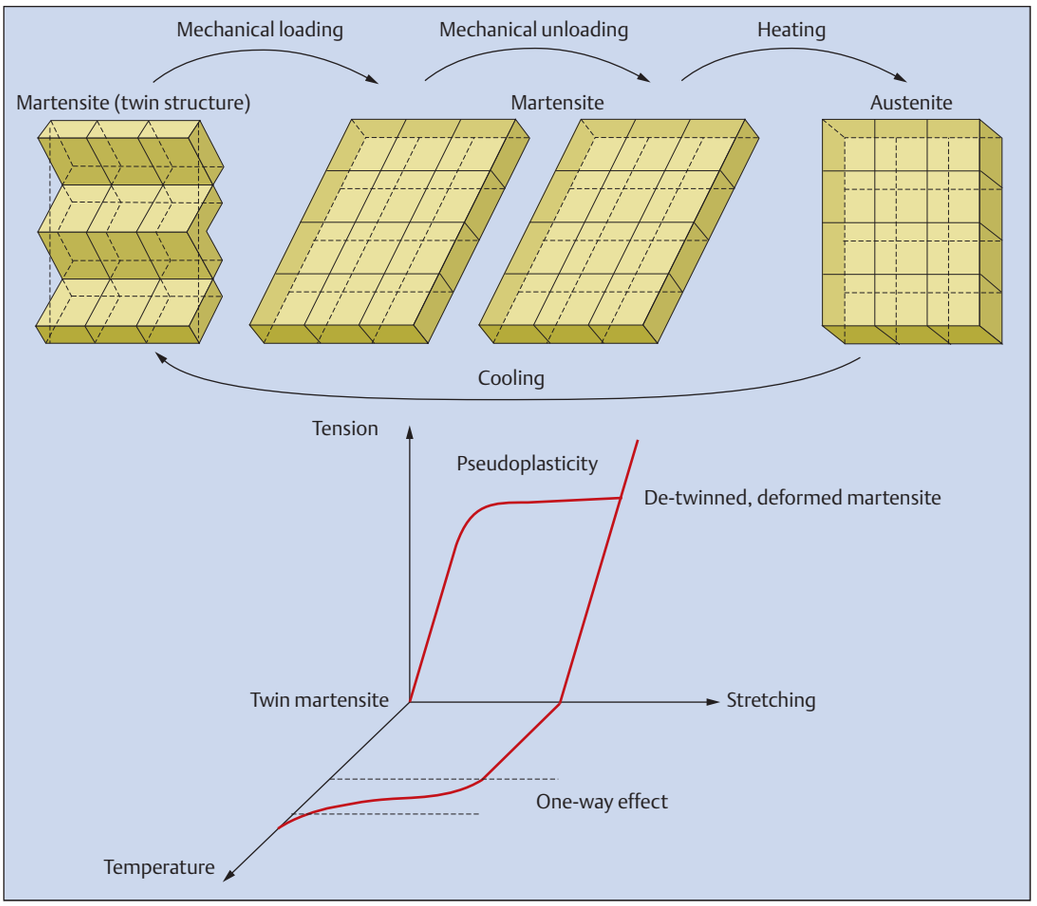
10.1 Pseudoelasticity

Alloys with memory effect (e.g., NiTi) do not show volume changes during phase change (courtesy of D. Helm).



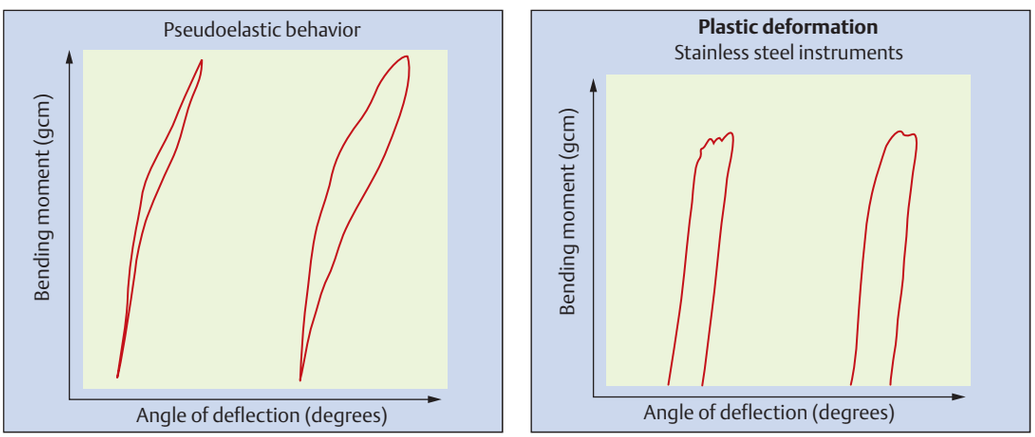
10.2 One-way effect

On the basis of the principle of one-way effect, the macroscopic similarity of the twin form of martensite (left) with the austenite form (right) has been exploited. Pseudoplastic deformation occurs as the twin crystals of martensite are deformed in a predestined direction without breaking (middle). Heating leads to conversion to austenite, and renewed cooling results in transformation into martensite (adapted from D. Helm).



NiTi exhibits virtually no change in volume on cooling and heating, because the twinned martensite and austenite phases are virtually identical in macroscopic measurements. The biocompatibility of Nitinol is very good (Ryhanen et al., 1999), and it is used extensively in medicine and dentistry today. The high content of nickel is apparently not problematic because it is bound to the titanium and therefore does not elicit any of the known nickel allergies (Schäfer, 2002a). However, the manufacturing process is difficult and expensive, and previously often led to inconsistencies.

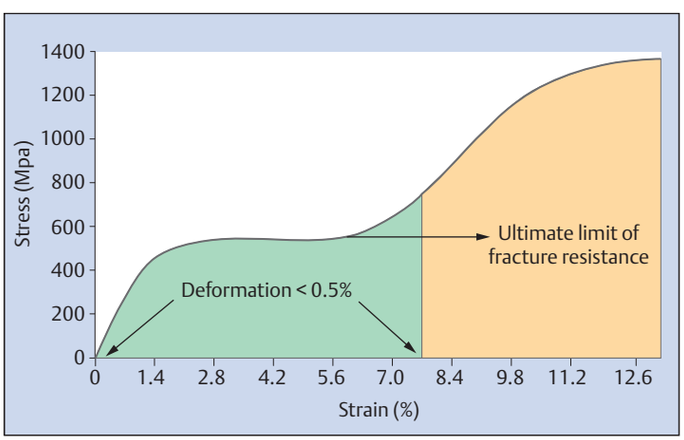
The low hardness (HV 300–360) and the resultant low cutting efficiency of NiTi in contrast with stainless steel (HV 520–540) are outweighed by the ability to use it with a rotatory motion. However, the lower cutting efficiency of NiTi files also means reduced longevity. To counteract this disadvantage, various groups have attempted to improve the surface qualities of instruments, by using nitrides, bromides, or nitrogen ions (Lee et al., 1996; Rapisarda et al., 2000, 2001). Using the technique of physical vapor deposition Schäfer (2002b, c) applied a titanium nitride layer, which led to improved cutting efficiency.



10.3 Hysteresis curve: NiTi versus steel

Left: When a NiTi file is bent, it returns to its original shape and position (Schäfer, 2002a).

Right: In contrast, if a steel file is bent, the result is a permanent, plastic deformation (Schäfer, 2002a, with permission).



10.4 Breaking strength of NiTi

Owing to the special property of superelasticity, NiTi instruments can withstand twisting up to 8% without incurring any permanent deformation (left plateau). Furthermore, deformations up to 12% do not necessarily lead to instrument fracture, but ultimately lead to the point of potential fracture (Thompson, 2000, with permission).

10.5 PVD coating

Attempts to enhance the surface stability have, to date, often only been of experimental nature. The few instruments available to date include the Naviflex TiN files. In the technique developed by Schäfer (Münster), the PVD coating with titanium nitride enhances the file hardness and resistance to abrasion. (Reamers, H files and—as depicted here—K files: Brasseler, Lemgo, Germany).

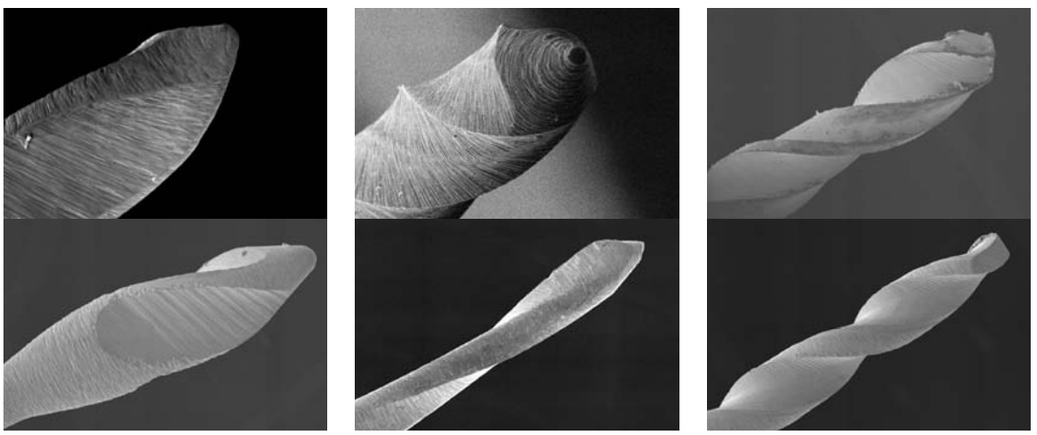
Design of Nickel-titanium Files

Permanently rotating instrumentation using NiTi files has been in vogue for almost two decades. But the period of development of such files has a much longer timespan. Walia et al. (1988) initiated the development by imitating the shape of a K file.

The first commercially available systems—LightSpeed, Mity Roto, ProFile, and Power-R—had flattened cutting edges ("radial lands"), and there was initially some fear that these edges would cut too quickly into dentin, leading to wedging and finally to instrument fracture. In fact, this fear was substantiated by subsequent studies of fracture rates (Baumann and Roth, 1999).

The file tip and the cutting edges were first rounded to provide a non-cutting pilot tip or a "safety" tip. Over time, other, more active, shapes were developed. The aggressive cutting by the earliest Quantec files (wedge-form, with 60° and 90°) led to obvious alterations in the internal root canal wall configuration, with massive "elbow" formations (Thomspon and Dummer, 1998).

For the most part, today's instruments have a rounded tip, and the cutting edges retain their sharpness right up to the tip.

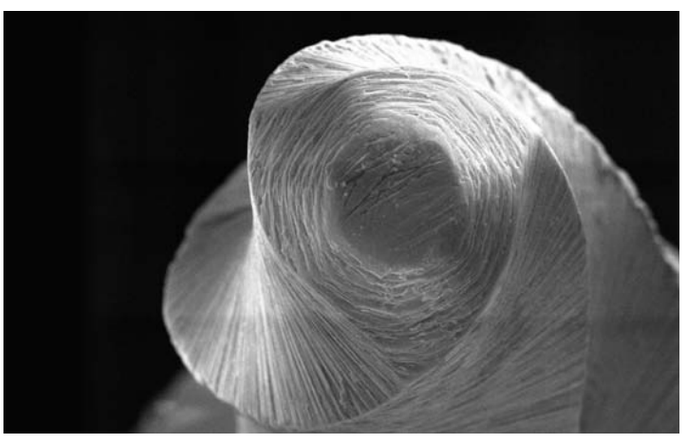


10.6 File tip shape

Left: Many NiTi files have a rounded tip; this provides guidance without alteration of the canal wall (above: ProFile; below: LightSpeed).

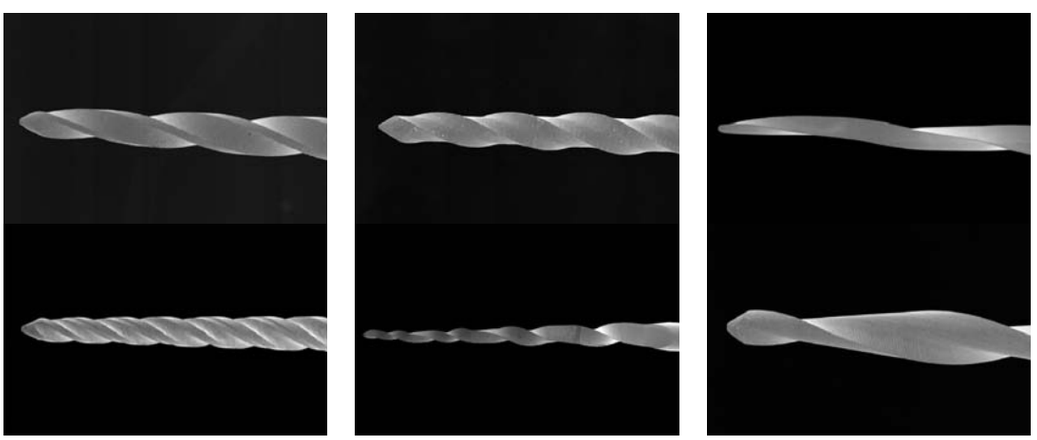
Middle: The tip of the FlexMaster file (upper panel) ends in a point, and the cutting surfaces extend forward so that on the application of pressure the cutting edges engage the dentin. Mtwo files are less sharp (lower panel).

Right: Initially, Quantec files had a 90° angle and created rather severe canal alterations (upper panel), but this was reduced with the introduction of the safe-cutting tip (lower panel).



10.7 File tip detail

This direct view of the Introfile (VDW, Munich) shows that the sharp cutting edges extend almost to the instrument tip and therefore have the capacity to cut dentin on application of pressure. The surface of the file as shown in this scanning electron micrograph illustration is rough and does not cut in a uniform manner.



10.8 Configuration of the cutting edges

Left: A basic principle is flattening of the cutting edges (upper panel: Profile; lower panel: Quantec).

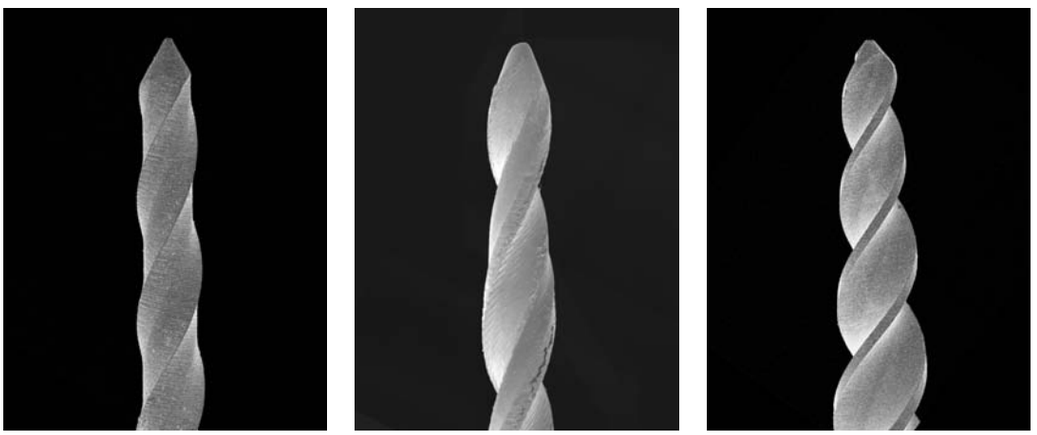
Middle: Sharp cutting edges mean greater dentin removal (upper panel: FlexMaster), but run a risk of screwing. For this reason other designs like alternating cutting edges were developed (lower panel: RaCe).

Right: Contemporary instruments have delicate yet sharp cutting edges (upper panel: Rondo), and also exhibit an undulating form (below: Mtwo).

The chip space is an important characteristic, as it determines how much debris can be removed before the file becomes stuck in the canal. Endodontic instruments must therefore possess a blend of desirable characteristics that include flexibility, fracture resistance, and stiffness.

While traditional instruments always had the same chip space, with the development of NiTi instruments, even early on—since 1998 with GT—there was an attempt to increase the distance between the flutes, which increased the chip space, reduced the tendency for file wedging during rotation, and permitted more rapid instrumentation. Particularly noteworthy is the alternation between straight and twisted areas in the RaCe line of files. Many instruments today have a progressive distance between cutting edges (e.g., ProTaper, Mtwo).

The taper of NiTi files is also an important characteristic; from 0%—"no taper"—in the case of LightSpeed, to the now common 2%, 4%, and 6% taper, up to even 19%. More recent is the "reverse taper" design, such as ProTaper or S-Apex instruments, which are thicker at the tip than throughout the body of the file. In addition, the same instrument has multiple tapers (f1: 7% up to 3 mm from the tip, then 5% e.g., the ProTaper and the later developed ProTaper Universal).

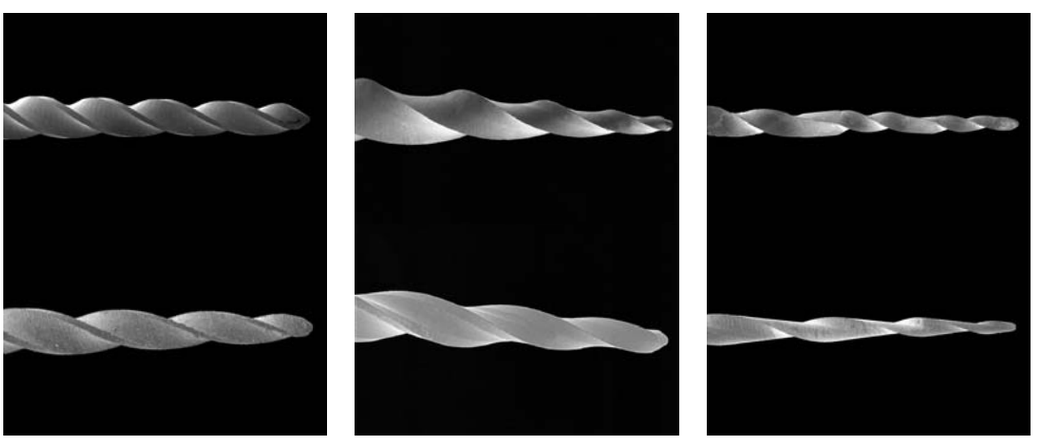


10.9 Amount of chip space

Left: Instruments with a convex triangular cross section (FlexMaster or ProTaper) have a smaller chip space.

Middle: Quantec LX had greater chip space, which increases efficiency of removal of dentin debris.

Right: The increased distance between the cutting edges, in combination with a U-shaped cross section, provides a significantly increased cutting angle in the GT files.



10.10 Cutting edge distance

Left: ProFiles have a regular and constant flute distance (upper panel), but with GT files (lower panel) there was an attempt to increase the distance between cutting edges.

Middle: Progressively increasing distance between the cutting edges is a common aspect of contemporary endodontic instruments (upper panel: Introfile; lower panel: ProTaper).

Right: A characteristic of the RaCe instrument (upper panel) is the alternating straight and twisted regions. Mtwo exhibits extremely thin and wide cutting surfaces (lower panel).

10.11 File taper

Left: GT files were the first NiTi files with a very high taper of up to 12%.

Middle: The S-Apex instrument reversed the development and is actually thicker at the tip compared with the shaft of the instrument. The file is almost parallel, and is commercially available in sizes 15–40.

Right: Also in the ProTaper group, the finishing files (FF1–3) have a taper of 7%, 8%, and 9%, higher at the tip than in the rest of the file shaft, which is 5%.

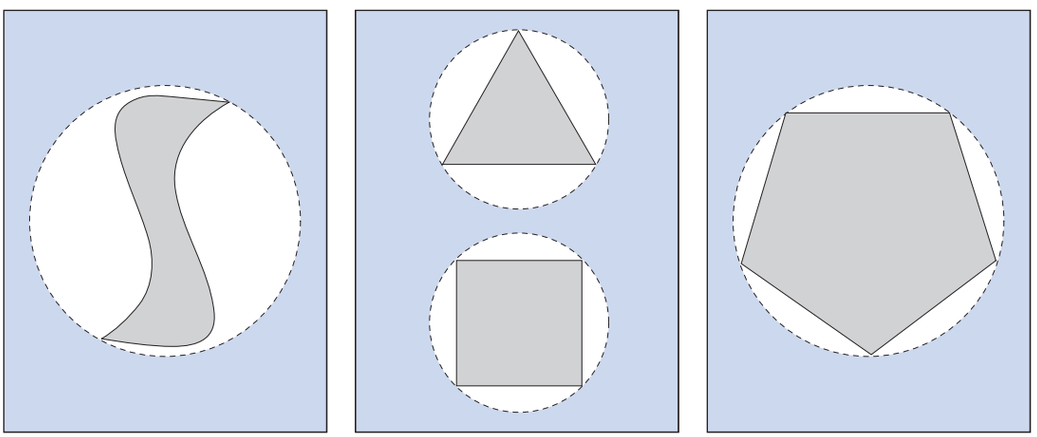
Cross Section of Nickel-titanium Files

The U-shape has been modified many times, and only in 1999 was it presented as a commercial entity in systems such as Hero 642, FlexMaster, RaCe, etc., with sharp-cutting modified K files.

Quantec and K3 looked at other options with more complex cross sections. The basic shape of the triangular cross section with a flattened tip and a U-shape depression was varied in that the central area was enlarged for stabilization, while the cutting surfaces were made ever sharper, combined with more obliquely oriented surfaces to remove dentin chips and debris.

In subsequent modifications, the basic form was changed to that of an S file or Unifile, and the transverse section modified to resemble a pentagon (Alpha file). Above all, the triangular cross-section permits numerous modifications, many of which are available commercially today. The square cross section—still common in steel—is found today only in RaCe instruments.

Most recent developments, such as Mtwo, capitalize on the sharpness of the Hedström (H) file design, using—as the name suggests—two cutting surfaces. The progressively increasing distance (chip space) between the cutting surfaces from the proximal to the distal end permits a higher level of material transport.

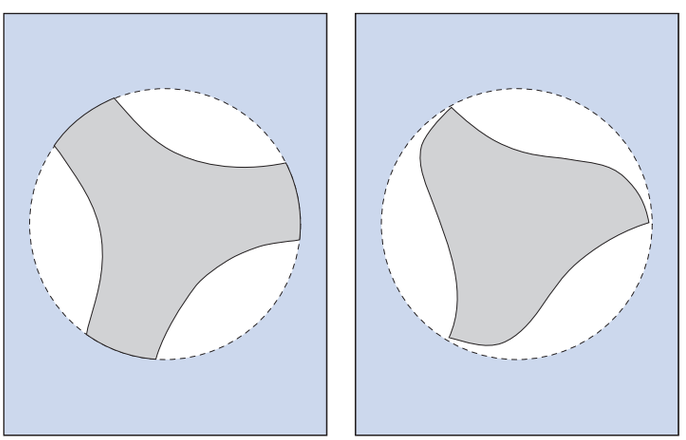


10.12 Cross section of NiTi files I

(Diagrams courtesy of H. Walsch.) Left: The S-shaped cross section was first seen in the NiTi Tee, and continues to find successful application in the Mtwo instrument line. A larger chip space, softer surfaces, and increased flexibility are provided by the Tempo and Efficients files.

Middle: Modern triangular and square cross-sectional instruments evolved from the original steel instruments, and there are numerous variations available.

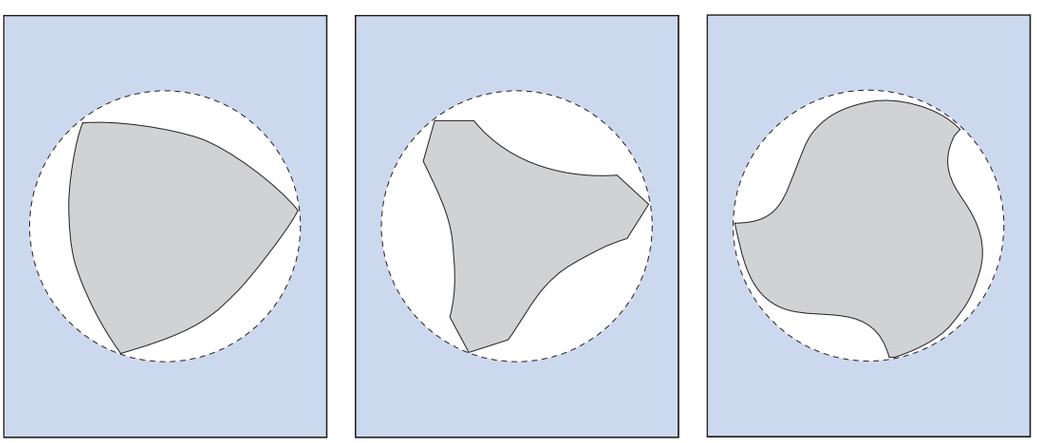
Right: The pentagonal cross section is the basis for the Alpha file.



10.13 Cross section of NiTi files II

Left: By rounding off the corners of a triangle to get a smooth profile, the basic form of many NiTi files, the U-form, is achieved (e.g., ProFile, GT files).

Middle: Instead of rounded-off cutting edges, they are smoothened so that the final cross section of the inter-flute region is S-shaped. The result is a somewhat larger chip space, which allows improved removal of dentin.



10.14 Cross section of NiTi files III

Left: The expanded triangle resembles the Wankel automotive engine, and is described as a convex triangle. This basic shape is typical for FlexMaster and ProTaper.

Middle: If the convex sides of the triangles are carved U-shaped, the instrument will be more flexible, a concept that is utilized to advantage in the ProTaper files FF3–FF5.

Right: More complex shapes with a larger central diameter reduce the cutting edge distance and also reduce file flexibility (Quantec, K3).

In recent years, an increasing number of file systems have appeared on the market with quite different geometries. During this rapid period of development it has been difficult for the dentist/endodontist and also the various professional organizations to order or categorize the numerous and variable endodontic instruments.

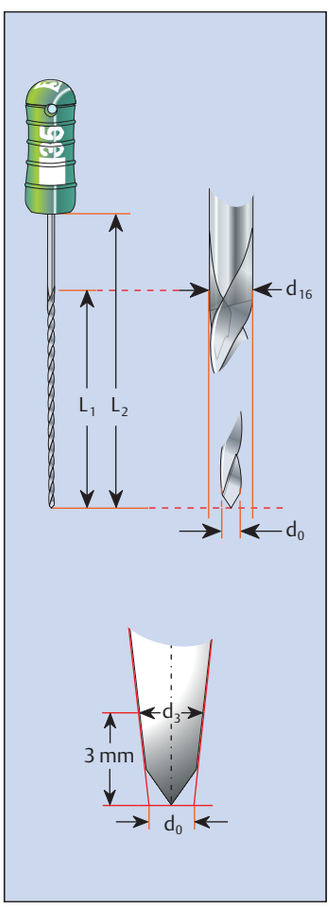
The success of any NiTi system depends not only on the cutting efficiency of the file, but also to a great extent on the ease of use and the logic behind the file sequence. As early as 2002, Ehrmann called for standardization and simplification of the endodontic file coding system.

Although the ISO color coding scheme is still determined by the diameter of the file tip, based on older regulations (which often today are no longer relevant or applicable), the *taper* of 0–19%, which is often inverse and multiple, is not always easy to comprehend. Thus, the dentist/endodontist is left with an almost innumerable array of file geometries that are often difficult to categorize. The one helpful factor in this arena of confusion is the commercially available instrument organizers.

10.15 "Wash box" and Alutray

The LavEndo (VDW, Munich) represents an intelligent solution for cleaning instruments, providing ease of placement in a thermal disinfector, and subsequent transfer of the instruments to the dustproof endodontic box.

Left: The classic LightSpeed instruments are available in 22 configurations and provided in a foam container to achieve clinical standardization of presentation.



Color code	ISO size	$d_0 \pm 0.02$ mm	$d_{16} \pm 0.02$ mm
	006	0.06	0.38
	008	0.08	0.40
	010	0.10	0.42
	015	0.15	0.47
	020	0.20	0.52
	025	0.25	0.57
	030	0.30	0.62
	035	0.35	0.67
	040	0.40	0.72
	045	0.45	0.77
	050	0.50	0.82
	055	0.55	0.87
	060	0.60	0.92
	070	0.70	1.02
	080	0.80	1.12
	090	0.90	1.22
	100	1.00	1.32
	110	1.10	1.42
	120	1.20	1.52
	130	1.30	1.62
	140	1.40	1.72

10.16 ISO standardization

The dimensions of endodontic instruments are determined according to ISO standards. A color-coded system permits rapid visual recognition of an instrument's diameter.

The three smallest sizes (size 6 = pink; 8 = gray; and 10 violet) are followed by three sequences of white – yellow – red – blue – green – black.

Left: The cutting surface area extends over, according to ISO standards, 16 mm (L_1) of the total length, which is measured from the tip of the instrument to the point where it joins the handle (L_2). Three different diameters are recognized: d_0 at the tip, d_{16} at the end of the working length at 16 mm, whereas d_3 is 3 mm proximal to the tip.

11 Irrigation, Drying, Medicated Dressings

Sodium hypochlorite (0.5%–6%) remains today the most frequently used irrigating solution. Its primary advantage is its unique tissue-dissolving effect, which is increased at higher concentrations; at 5.25% it requires only about 30 minutes to completely dissolve pulpal tissues (Türkün and Cengiz, 1997). The antibacterial effect appears to be only partially based on concentration (Byström and Sundqvist, 1983; Siqueira et al., 2000), whereas the fungicidal effect is better at higher concentrations (Sen et al., 1999). Sodium hypochlorite is, however, not effective against *Enterococcus faecalis*, and chlorhexidine (CHX) is the best alternative.

Chlorhexidine can be used as an irrigating solution or a root canal dressing (in gel form) and has fungicidal as well as antibacterial effects. Its low toxicity and depot effect (substantivity: Komorowski et al., 2000) make it virtually indispensable today in cases of pulpal necrosis and endodontic retreatment.

Bacterial growth is enhanced in canals not treated with a medicated dressing (Byström and Sundqvist, 1981, 1985). According to an evidence-based analysis (Law and Messer, 2004) calcium hydroxide is the medicament of choice and should be left in situ for at least 7 days.

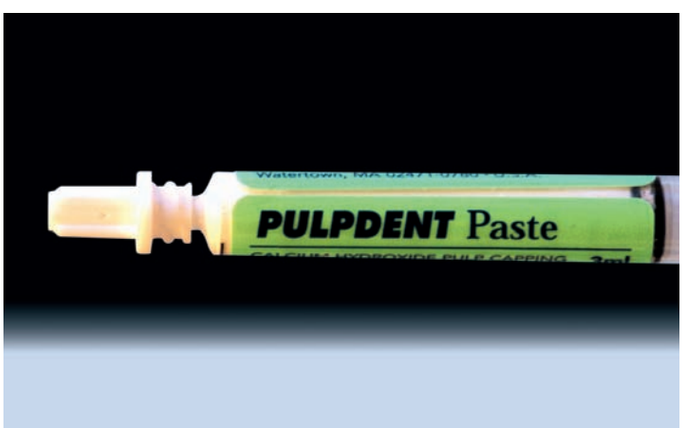
11.1 Heating the irrigating solution

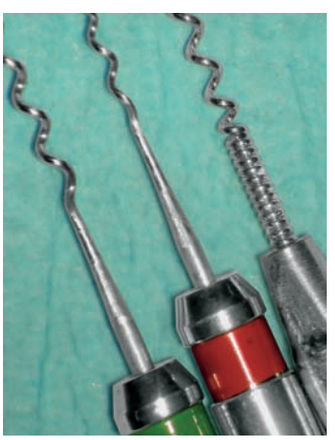
Heating sodium hypochlorite solution to 50–60°C enhances its tissue-dissolving and disinfectant effects. In addition to devices designed in individual practices for heating the irrigating solution, there are several commercially available devices that provide precise temperature control (Syringer warmer, ADS, Germany).

11.2 Medicated dressings

Even today, a watery paste of calcium hydroxide is the most important material for use as an interim root canal dressing. The most commonly used commercial agent is Pulpdent (Pulpdent Corp., Watertown, MA, USA).

Right: The lentulo spiral is the most reliable instrument for carrying the calcium hydroxide paste into the root canal. Instruments with a rigid shaft have an increased risk of fracture, whereas a spiral tip in front of the contra-angle shaft is safer.

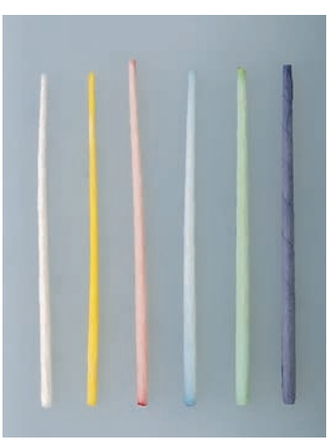




11.3 Drying

Left: In addition to alcohol, paper points remain the method of choice for drying the root canal. Many commercially available tips come in various color-coded sizes that correspond to ISO color codes.

Right: In keeping with the raised standards of hygiene within the dental practice, the paper points are sterilized and packed in small numbers, either ISO color coded or in white.



12 Sonic and Ultrasonic Treatment

The term "sonic" refers to sound waves in the region of 16 Hz up to 20 kHz, whereas ultrasonic waves range from 20 kHz to 1 GHz. Over 50 years ago, Richman (1957) first described the use of ultrasonic technology in endodontic treatment and root tip resection. Almost 20 years elapsed before the use of ultrasonic technology was again pursued (Martin, 1976). Thereafter, numerous scientific publications appeared (literature reviews: Hülsmann, 2000; Haapasalo et al., 2005) indicating the possibilities and potential significance of sonic and ultrasonic devices in endodontology. These are based on three mechanisms of action:

- cavitation;
- production of heat;
- acoustic microstreaming.

Most of the research of the past 30 years has been targeted toward the use of sonic and ultrasonic devices as replacements for, or enhancement of, traditional, manual root canal instrumentation, and synergistic action with irrigating solutions. The past decade brought a total paradigm shift: Today, the primary areas of use include disengaging and loosening of intracanal obstructions, endodontic retreatment, and retrograde treatment approaches. The three mechanisms of action of ultrasonic devices have been evaluated time and again with varying results, but in principle they are generally recognized as being effective (van der Sluis, 2006).

An ultrasonic generator (usually piezoelectric) causes the files to oscillate with an undulating wave pattern with a series of nodes and antinodes along its length. The continuous waves help in the removal of dentin chips and debris; the action is strongest at the tip where the amplitude of the oscillations is the largest (Ahmad et al., 1992). Ultrasonic waves in the presence of liquids results in massive oscillation with regions of high and low pressure. This phenomenon is known as *cavitation*. The result includes bubble formation within the liquid, as well as turbulent fluid currents. The microbubbles created may be empty, or may contain gas or vapor. With the use of sodium hypochlorite, it is possible to achieve a warming effect above the boiling point of 40°C, which leads to the formation of the Na+ cation, the hypochlorite anion ClO, as well as the formation of NaOH, ClOH, C12, O, or NaCl (van der Sluis et al., 2006). These highly reactive elements may be the reason for the observation that the antibacterial effect of ultrasound in the presence of water is relatively weak (Ahmad et al., 1990), but is much stronger with typical endodontic irrigating solutions, providing a large antibacterial effect (Cameron, 1987; Huque et al., 1998).

With the application of high acoustic pressure, the microbubbles enlarge until they eventually implode, creating strong local pressure waves as well as a rise in temperature (*heat*). This physical principle is also exploited in devices such as the urolithotripter, which is used for the destruction of gallstones or kidney stones. In comparison, the instruments designed for use in the dental practice are too weak to create large cavitation effects. For this reason, the effect has been considered by numerous authors as too mild and thus ineffective (Ahmad et al., 1987b, 1988; Walmsley 1987; Lumley et al., 1988).

Most important and effective is the third mechanism of action: *acoustic microstreaming*. Within the sonic field, there is an interaction between the sonic file oscillations and the irrigating solution, which leads to motion within the fluid, the so-called "eddy current." This current flows from the coronal end of the root canal toward the apical area and exhibits the typical nodes and antinodes; it is strongest at the tip (van der Sluis, 2006). Due to the higher level of energy, the eddy currents that are created elicit hydrodynamic shear stresses, which have been demonstrated in many studies (Ahmad et al., 1987a, b, 1992; Lumley et al., 1991; Walmsley et al., 1992, Roy et al., 1994). Contact of the sonic or ultrasonic probe with the internal surface of the root canal reduces acoustic microstreaming by interrupting the continuous motion of the wave, but does not eliminate it completely.

Sonic Systems

Sonic devices operate at 1500–6000 Hz. Included in this category, are, for example, Endostar (Syntex, USA), Megasonic 1400 (Megasonic, USA), and Sonic Air MM 1500 (MICRO-MEGA, France). Special instruments are required (e.g., heli-, rispi-, shaper-, or trio-sonic files), some of which resemble traditional rasps. The Shaper-Sonic files in particular permit rapid removal of dentin remnants and debris; this is due to the design of the instruments, but also because sonic devices are much better at removing hard substances than ultrasonic devices (Miserendino et al., 1988).

In general, files of smaller diameter are more effective. The higher amplitude of motion at the file tip is advantageous in comparison with ultrasonics, but is counteracted by the fact that the degree of dentin transport is more difficult to control and there is some loss of tactile sensitivity.

In addition, instrument fractures and complications such as step formation, loss of working length, etc., occur less frequently with sonic than with ultrasonic devices. There remains some controversy concerning effect on canal shaping and roughness due to the file design (Loushine et al., 1989). For these reasons, sonic systems have not been widely accepted for use in endodontic practice.

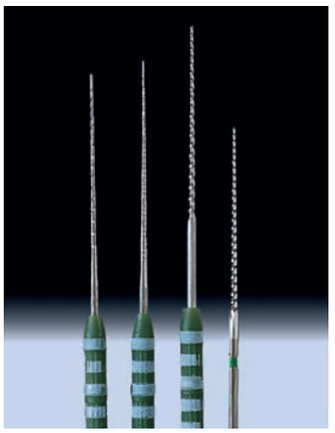
12.1 Sonic instrumentation

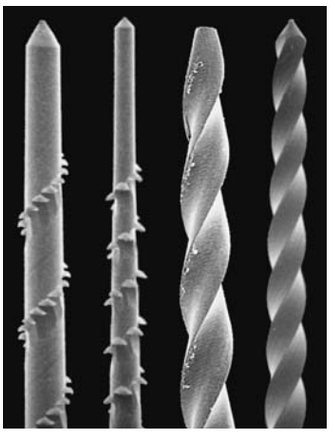
Low amplitudes of up to 6000 Hz provide the activity frequency for sonic instruments.

Left: The MICRO-MEGA Sonic Air 1500 handpiece with a sonic file.

Middle: Special instruments for sonic/ultrasonic instrumentation. From left to right: Shaper, Rispisonic, Helisonic (S, MICRO-MEGA) and Endosonore files (Ultrasonic, Maillefer).

Right: Shaper and Rispisonic have a new design with spirally coursing projections, while the other commercially available instruments have a familiar appearance.





Ultrasonic Systems

Ultrasonic devices operate between 20 000 Hz and 40 000 Hz. Included in this category of instruments are the Piezon Master 400 (EMS, Switzerland), P5 or PMax (Satelec, Germany), Enac (Osada, Japan), and Ultrasonic Endo J15 (Spartan, USA). The earlier electromagnetic devices have, today, for the most part been replaced by piezoelectric devices in which a quartz crystal is set into vibration by the application of an electric current. Significant advantages are lower heat development, so that the handpiece does not need extra cooling, and improved transfer of energy from the handpiece to the file (Ahmad et al., 1992).

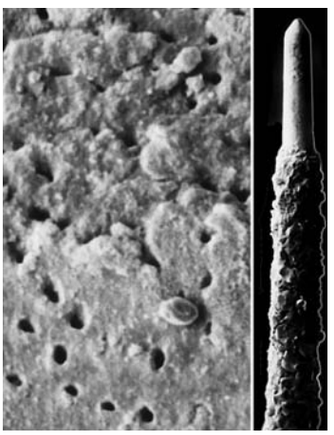
Ultrasonic instruments are for the most part similar to conventional K files. Thin files are more effective because they can oscillate more freely within the delicate root canal, and the oscillations are less susceptible to damping by contact with the root canal walls (Ahmad et al., 1992). There is, however, no direct antibacterial effect (Ahmad et al., 1990). Ultrasonic activation of the irrigating solution does not in any way reduce the debris or smear layer (Mayer et al., 2002), except with EDTAC (Guerisoli et al., 2002). However, canal shaping is difficult to control. Perforations, steps, and ledges frequently occur, so that ultrasonic root canal preparation is no longer justified (van der Sluis, 2006).

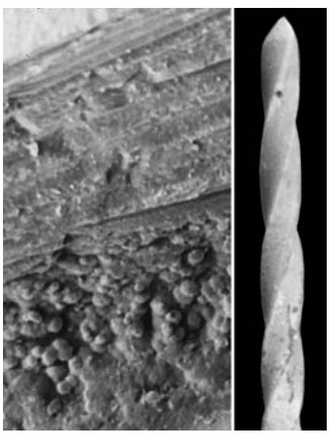
12.2 Ultrasonic instrumentation

Left: The Piezon Master 400 ultrasonic device (System 401, EMS) and Suprasson (Satelec) resemble a conventional dental handpiece. The CaviEndo (DeTrey) is a lamellated system and has a different appearance from that of the handpiece attachment of the sonic device (Meca Sonic 1400; MICRO-MEGA, left).

Middle: The diamond-coated ultrasonic files (DeTrey) create significant roughness.

Right: The ultrasonic K file lays bare the dentinal tubules. The canal wall is clean.





Passive Ultrasonic Irrigation

Since Sonic and/or ultrasonic devices proved unsuitable for "active" instrumentation of the root canal, in recent years the so-called "passive ultrasonic irrigation" (PUI) concept has emerged (van der Sluis, 2006).

Described as early as 1985 by Weller et al. the term "passive" described the sonic or ultrasonic activation of a root canal file that does not contribute to the actual instrumentation (dentin removal) within a fluid-filled root canal. This procedure is in accordance with the principle of first *shaping* the root canal and only then performing cleaning and disinfection (Castelluci, 2006).

As early as 1987, Ahmad et al. (1987a, b) demonstrated that cavitation and acoustic microstreaming in an already instrumented root canal were more effective. Recent research studies have again shown improved irrigation for instrumentation with 10% taper compared with 4% (van der Sluis et al., 2005a).

Manual injection of irrigation fluids removes less debris, bacteria, and pulpal-tissue remnants than PUI (van der Sluis, 2006). Instead of using files, which also remove hard substance from the internal surface of the root canal, the trend today is to use a smooth wire, which does not affect the canal wall shape but removes debris equally well (Mayer et al., 2002; van der Sluis et al., 2006). In this regard it is possible to differentiate two types of cavitation (van der Sluis, 2006):

- *Stable cavitation*: This occurs primarily around the middle of the file and is characterized as "a linearly pulsating, gas-filled body within a sonic field of low amplitude."
- *Transient cavitation*: This is characterized by "bubbles and high-energy pulsations," assuming there is free oscillation of the file within the canal. It also appears helpful to prebend the wire or the file for use in curved root canals (Ahmad et al., 1992; Lumley 1992).

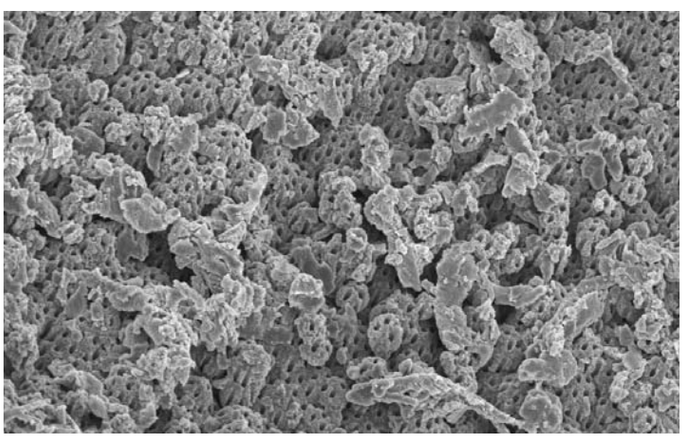
With PUI, use of sodium hypochlorite is of importance, because the smear layer, debris, and bacteria are more effectively removed than with just water (Huque et al., 1998; van der Sluis et al., 2006). The antibacterial effect is accounted for as follows:

- removal of planktonic bacteria;
- disruption of the biofilm;
- killing of bacteria (van der Sluis, 2006).

Pulpal tissue and debris are also effectively removed from within niches or isthmus configurations, which are often inaccessible with traditional root canal instrumentation (Lee et al., 2004; van der Sluis et al., 2005a, b). PUI is a significant development in the cleaning and disinfection of the root canal system.

12.3 Ultrasonic tips

In recent years, various sizes and shapes of ultrasonic tips have been developed. In contrast with earlier developments, the newest innovations are not simply modified K files, but rather they are often diamond-coated or zirconium nitride-coated, extremely fine, pointed tips (seen here: ProUltra tips, Dentsply Maillefer). These tips are important and even indispensable for reinstrumentation of previously treated canals and removal of broken instruments or points, and root canal calcifications or obstructions.



12.4 Scanning electron photomicrograph

An experimental brush fitted on the head of a sonic toothbrush provided a good cleaning effect, with exposure of the dentinal tubules (courtesy of I. Salman).

Paradigm Shift: New Uses for Ultrasonics

From early on, the focus was on the use of sonic and ultrasonic devices primarily for mechanical root canal instrumentation and numerous research studies were carried out. In retrospect, this approach was not correct. Only passive ultrasonic irrigation (PUI) has stood the test of time. Today, the primary use for ultrasonics in endodontology is in the targeted search for and opening of canal orifices or in retreatment of previous failed endodontic attempts (Ruddle, 2002; removal of fractured instruments, old root canal fillings, pins/posts etc.), aspects also considered earlier by various authors (Meidinger and Kabes, 1985; Stamos et al., 1985).

Today's modern ultrasonic generators produce higher energy that can be better regulated, without frequency variation. The material and design of ultrasonic files have received considerable attention. In addition to steel instruments, today's endodontic armamentarium includes instruments made of titanium and zirconium nitride, and often also instruments with diamond-coated surfaces (Lin et al., 2006). A variety of tips are available for target-oriented performance of various tasks (of appropriate thickness for debris removal, pin/post removal, eliminating canal obstructions; or different angulations or retrograde instrumentation).

12.5 Initial situation

(Case courtesy of Professor Linden.)
Left: The initial diagnostic radiograph reveals apical lesions in relation to both the roots of tooth 46, as well as a deficient restoration on the distal aspect.

Right: This radiograph, taken for canal length determination, shows three Hedström files, all of which are clearly too short of the correct working length.

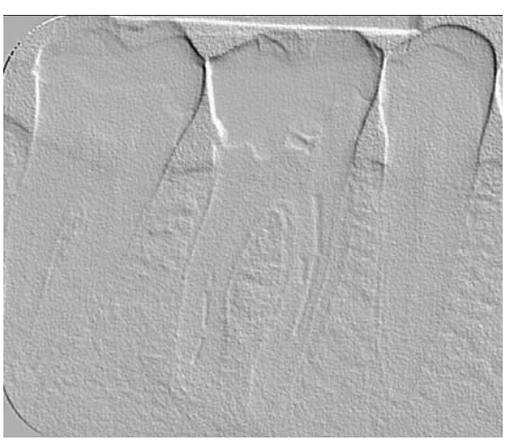
12.6 Multiple instrument fracture

Subsequent radiograph showing five separate instrument fragments and enlargement of the apical radiolucencies.

12.7 Initial situation before beginning treatment

Left: This digital radiograph shows six radio-opacities indicating broken instruments. The apical radiolucency has again increased significantly in size.

Right: High-contrast representation for improved visualization.



The *reinstrumentation of previous root canal treatment* has long been a difficult task. Ultrasonics and the clinical microscope have opened completely new and unexpected possibilities. Early studies demonstrated that the success rate, for example for the removal of fractured instruments, could be elevated from 68% (Hülsman and Schinkel, 1999) to 87% (Suter et al., 2005).

In the interest of improved visibility, the use of water cooling was often avoided. The temperature increase during pin removal was measured at 21.1 ± 27.9°C and on the root itself 10.9 ± 7.9°C, but air cooling brought some relief (Budd et al., 2005).

The surgical *apicoectomy procedure* without the use of ultrasonics and the clinical microscope is no longer even imaginable. Authors and researchers such as Carr, Kim, Stropko and others established a completely new and tissue-friendly method (see Microsurgery chapter).

Various long-term investigations have demonstrated that microsurgical procedures are significantly better than the conventional methods, with success rates above 90% (Rubinstein and Kim, 2002: 91.5%; Maddalone and Gagliani, 2003: 92.5%; Taschieri et al., 2006: 92.95%; Tsesis et al., 2006: 91.1%).

12.8 Intraoperative radiograph

Left: Following removal of five of the six fractured instruments (using the technique as described by C. Ruddle), the single remaining fragment is visible in the distal canal.

Right: Radiograph following removal of the sixth fragment and placement of a calcium-hydroxide dressing.

12.9 Canal length determination

Once all the apical foramina were visible through the microscope, a new radiograph was taken for precise root canal length determination.

12.10 Radiograph follow-up

Left: Heated vertical obturation was carried out. It is possible to see the complete sealing of the mesial apical region, as well as the lateral distal expanse of the root canal filling material.

Right: At 7 months after treatment there is significant healing.

13 Lasers

In dentistry, the use of lasers in endodontic treatment is of increasing interest. Advances in laser technology and a better understanding of the effects of lasers have widened the spectrum of possible uses of lasers in endodontology. Various commercial laser systems (e.g., argon ion diode, neodymium:yttrium aluminum garnet [Nd:YAG], erbium:yttrium aluminum garnet [Er:YAG], and carbon dioxide [CO_2] lasers) are available for endodontic diagnostic procedures, treatment of cervical hypersensitivity, direct/indirect pulp capping, sterilization and/or instrumentation of the root canal, and for endodontic surgery. The development of newer delivery systems—using thinner and more flexible optical fibers—has resulted in an ever-increasing number of laser wave lengths, and the feasibility of many laser applications in endodontic therapy has greatly improved.

Despite the technical advances mentioned above, the use of lasers in endodontic practice in place of conventional procedures has not yet become widely accepted. This may be due in part to the relatively high initial investment costs, and also because in most clinical applications *laser-assisted* techniques are used, which complement conventional procedures but do not replace them.

13.1 Sirona diode laser

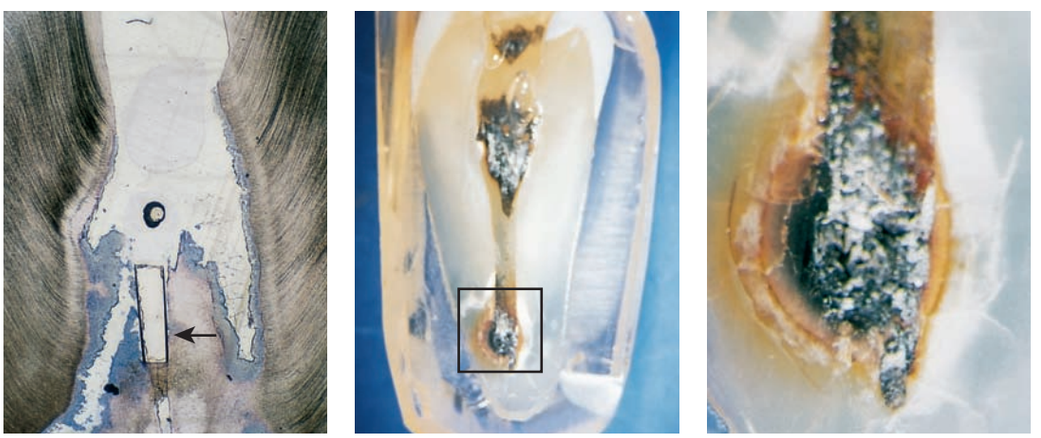
Example of a laser system for use in endodontics (diode laser/980 nm). The fibers have a diameter of 200–320 µm.

13.2 Possible adverse effects of laser use

Left: A fractured fiber within the root canal. The fiber fragment (arrow) could not be removed (thin section, magnification ×30).

Middle: Carbonization and dissolution on the root canal surface (inset) resulting from incorrect setting of laser parameters.

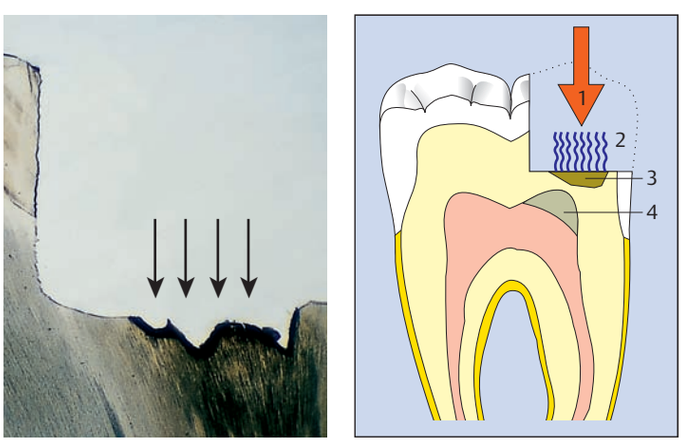
Right: Magnified image of the inset in the middle figure.



13.3 Indirect pulp capping using the CO_2 laser

Left: Histologic preparation following sealing of the dentin cavity with a CO_2 laser.

Right: Schematic of the sterilization and sealing of the surface of the decayed cavity. Following preparation and removal of the carious tissues, the dentin immediately adjacent to the pulp is exposed to the laser. The laser-induced "sealing" of the dentin is intended to stimulate additional formation of secondary (reparative) dentin.

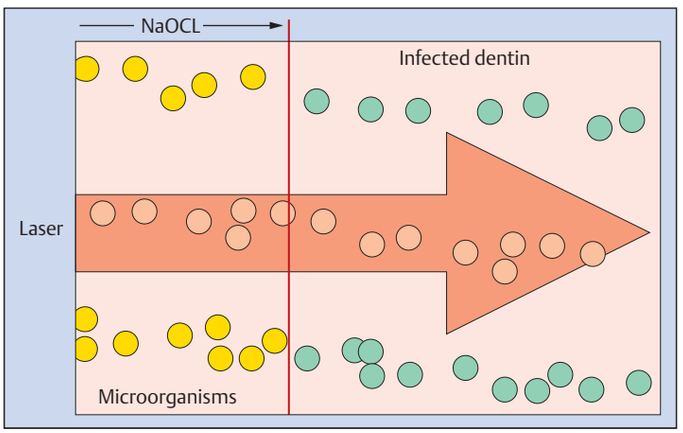


1 CO_2-laser
2 Water vapor
3 Sealed dentin layer
4 Formation of secondary (reparative) dentin

Lasers can be used for disinfection of the root canal, especially for reduction of the microbiologic flora in the infected canal walls. Today, the most popular lasers for endodontic application are the Nd:YAG and the diode laser. With these laser systems, optical fibers are available that can extend far into the apical regions following mechanical instrumentation of the root canal. The infrared laser beams can penetrate deep into dentin.

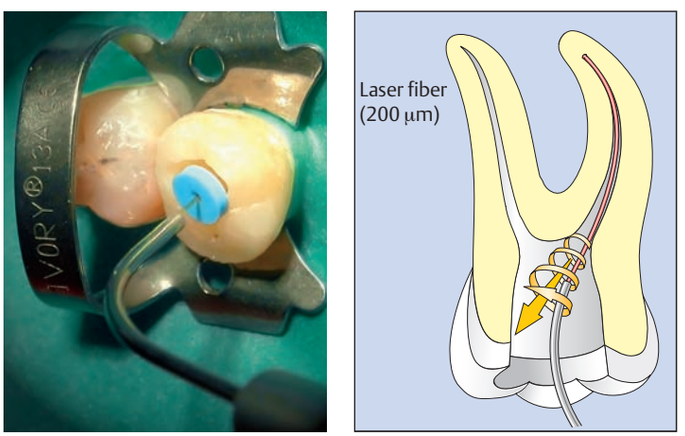
The biologic principle underlying the antimicrobial effect of lasers remains unclear. In addition to the active thermal-mediated destruction of microorganisms, there also seem to be photodynamic and mechanical (disruptive) effects resulting from the use of short-pulsed laser energy.

Under controlled test conditions, use of the above-mentioned laser systems has been shown to reduce the number of microorganisms in the root canal. For every laser system, clinical applications should be carried out within certain defined parameters in order to prevent damage to the periodontium, for instance. To enhance the antimicrobial effects, laser application can be combined with the use of conventional irrigating solutions (e.g., sodium hypochlorite).



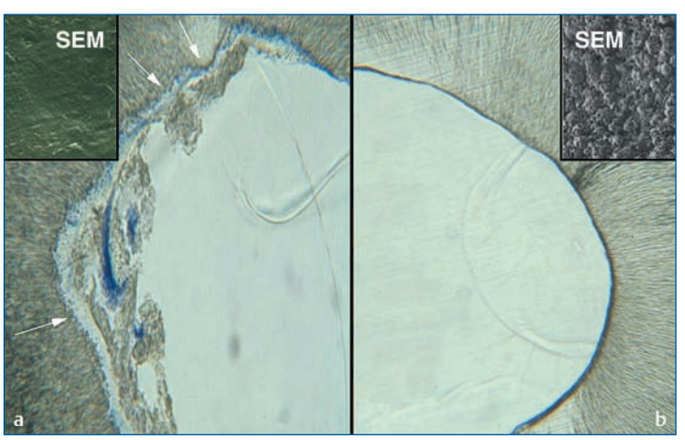
13.4 Penetration of the laser beam into dentin

Infrared radiation penetrates more deeply into dentin (>200 μm) than sodium hypochlorite, resulting in greater destruction of bacteria.



13.5 Fibers within the root canal

Laser fiber inserted in the root canal to disinfect the root canal dentin layer. The fiber is removed from the root canal in a circular fashion (approximately four rotations at 1 W; insertion up to 1 mm from the apical constriction).



13.6 Post-laser treatment clean canal wall

Through combined use of a Nd:YAG laser and sodium hypochlorite, the canal wall has been thoroughly cleaned.

a Before cleansing: visible tissue residue (arrow).

b After cleansing: the histologic section (×100) does not show any soft-tissue remnants, the smear layer, or open dentinal tubules (scanning electron microscopy, ×1000).

14 Gutta-percha

"Getah pertja" is a Malay term that means "fibers from sticky plant juices." The gutta-percha tree provides a raw substance (a gray, translucent mass with a reddish shine) for the dental material of the same name. Chemically it is an all-*trans* form of polyisoprene which is harder, more brittle, and less elastic than natural rubber.

The addition of softeners (1%–4%), metal sulfates (1%–15%, radiopaque), and zinc oxide as a main component (59%–76%) transforms the raw material into the "endodontic" gutta-percha (Friedman et al., 1975; Gurgel-Filho et al., 2003); this composition has remain unchanged for decades.

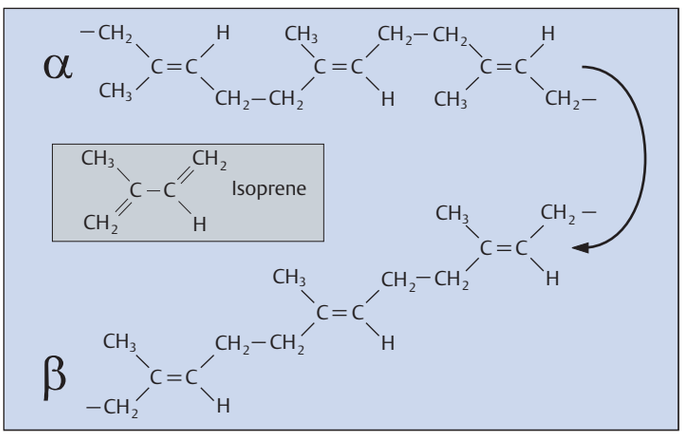
Dental-percha exists in two forms:

- α (more linear molecule);
- β (stairlike molecule);

For endodontic practice, as would be expected, dental gutta-percha is most often used in the β-form. The α-form is used only in combination with heating techniques (e.g., Obtura, Ultrafil, Thermafil). At raised temperatures, gutta-percha behaves like other plastic materials (Thermoplast): Softening above 65°C, melting at 100°C, and in the α-form beyond 160°C without decomposing while remaining soft and fluid.

14.1 Gutta-percha

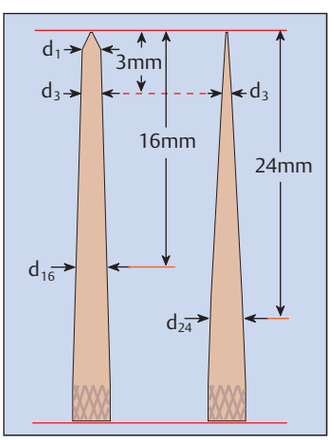
The sap of the isonandra gutta-tree provides the raw material for dental gutta-percha. Chemically, the substance is a polymer of the trans-form of the isoprene molecule. Normally, gutta-percha exists in the β-form (the typical dental gutta-percha points at room temperature). If gutta-percha is heated to 65 °C, its softening temperature, and slowly cooled (0.5 °C/h), the α-form exists at 42–49 °C. This is sticky, with a tendency toward becoming more fluid and is too soft to condense properly.

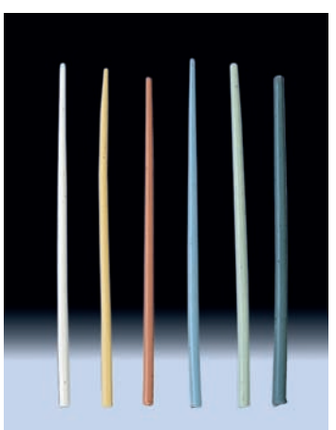


14.2 Gutta-percha points

Left: The sizes and dimensions of gutta-percha points are defined by various norms. International point norms have been established (d1 at the tip, is d3 3 mm proximal to the tip), but nonuniform-sized tips (right) are also available and have been described.

Right: Today, numerous gutta-percha points are commercially available and are color-coded to indicate the diameter; the colors are similar to the ISO colors.

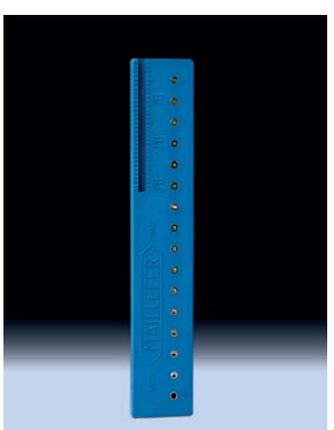


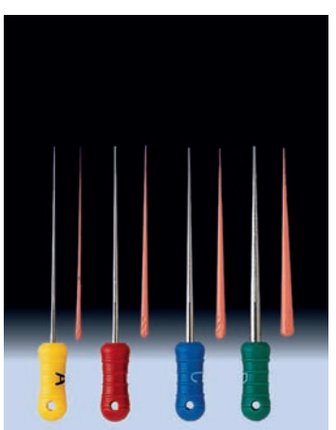


14.3 Determination of dimension

Left: For a long time, only about 50% of a given set of gutta-percha points corresponded to the norm, and there was immense variation, so it was helpful to develop a device with which the dentist could precisely measure the diameter of a gutta-percha tip (Dentsply Maillefer, Switzerland).

Right: While many nonstandard gutta-percha points do not correspond to the different sizes of spreaders, the taper of the points A–D corresponds precisely to that of the spreaders A–D (Dentsply Maillefer, Switzerland).





Gutta-percha has been used for many years for obturation of the root canal, and heating it—with the aim of filling more and finer canal areas—has been practiced for more than half a century. The past 10 years have seen modifications to the classic solid gutta-percha master point made of α gutta-percha because the increasing use of NiTi files of various geometries (4%, 6% taper, ProTaper, Mtwo form) required the root canal filling to adapt to the shape of the canal.

Furthermore, heated vertical compaction as well as other thermoplastic obturation techniques using gutta-percha continue to attract increasing attention from practitioners. There are several reasons for this, not the least of which is the development of not only new but also a larger array of devices (combination of spreader and backfill pistol, cordless devices, etc.) that are becoming increasingly easier and more reliable to use.

In addition, recently, more studies have questioned the long-term gold standard of "lateral compaction" and have provided evidence of excellent results with the heated vertical compaction technique (Farzaneh et al., 2004).

14.4 Gutta-percha variants

During the past decade, the form and composition of gutta-percha have been altered.

Left: Because of the popularity of NiTi files with higher taper, gutta-percha points are now commercially available with 4% (upper panel) and 6% (lower panel) taper.

Right: Gutta-percha points with calcium hydroxide (upper panel) make insertion easier. Similarly, the addition of chlorhexidine (lower panel) is of therapeutic interest and the gutta-percha is easy to use in most clinical situations.

14.5 Heated gutta-percha compaction

In the Schilder technique, gutta-percha points were heated over a flame. This was cumbersome and the temperature was poorly controlled. System B and Obtura were the first heat-producing devices that could be regulated.

Left: Cordless heated endodontic spreader that also delivers vibrations (DownPak, Hu-Friedy).

Right: Modern technology combines a heated spreader and a filling syringe into a single device, with precise temperature control (Sybron-Endo, Orange, CA, USA).

14.6 Heated compaction and obturation

Heated vertical compaction of gutta-percha points is today the gold standard for root canal obturation. While the "classic" Obtura device is currently in its third generation, newer developments in the form of cordless systems predominate, permitting greater freedom of movement (Meta E&A, ADS, Germany).

15 Retreatment

Optimized endodontic re-treatment of a previous failed endodontic attempt by means of orthograde removal of the filling material and fresh endodontic therapy is, according to the literature, a more predictable and more successful treatment compared with a retrograde surgical approach in the form of apicectomy (Allen et al., 1989; Molven et al., 1991). This is even more clinically relevant and important now, as new technical aids, particularly the clinical microscope, have made orthograde endodontic revision carried out under direct vision simpler, more precise, and ultimately more successful.

In the past, use of the Hedström (H) file, often in combination with dissolving/irrigating solutions, was the method of choice (Hunter et al., 1991; Hansen, 1998). In addition to the clearly most effective (but also most dangerous) chloroform solutions, numerous other agents such as halothane, xylol, or orange oil were also available. Nevertheless, all of these chemical agents are to some extent toxic, they do not significantly improve root canal cleaning or shorten treatment time. They are a limited treatment adjunct in cases of an over-compacted root canal filling, or in severely curved canals, but such solutions are today, for the most part, of historical interest only (Schirrmeister, 2006).

15.1 Dissolving solutions

For many years now, scientists have been researching agents for dissolving previously placed root canal fillings. The most recent studies indicate that root canal filling material can be dissolved, but the efficiency is quite low while the toxicity of the solutions may be quite high (depicted: Endosolve R and E, Septodont, Saint-Maure-des Fossés, France).

15.2 Hand and ultrasonic files

Hand instruments, in particular, the H files shown here, have been used for many years for reinstrumentation of previously treated root canals and are quite effective (H files with plasma vapor deposition [PVD] coating; Komet Brasseler, Lemgo, Germany).

15.3 Ultrasonics

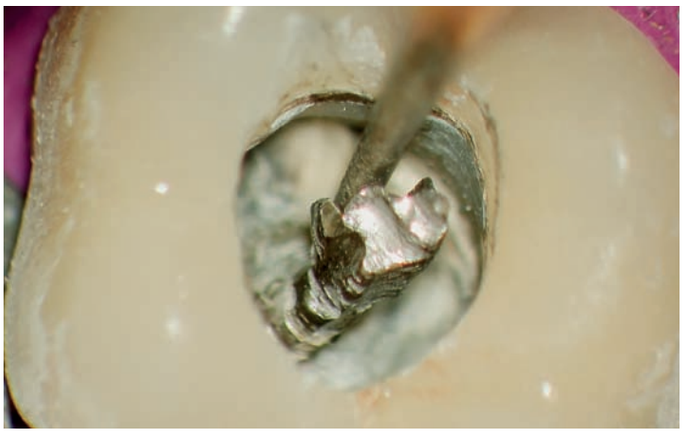
In today's contemporary practice, retreatment of root canals is unimaginable without the use of ultrasonic devices.

Right: In recent years, various shapes and forms of ultrasonic tips have found an important place in the retreatment of endodontic failures; with the use of the clinical microscope, the excellent vision permits the removal of the correct material, and by using very fine ultrasonic tips the revised preparation can be extended further apically.

Within the endodontic triad of "illumination, enlargement, and instrumentation" (see Microscopy, p. 123), several contemporary developments in instrument design have led to considerable simplification of, and faster, treatment. Nickel titanium (NiTi) files, special reinstrumentation files, as well as special handpieces and programs for this purpose in endodontic motors, represent major technologic advances. Initially, the NiTi files exhibited a higher taper (.04 [size 30] or .06 [size 30]), but over time special NiTi reinstrumentation files have been developed with cutting rather than rounded tips, which are easier to insert into and remove previously placed gutta-percha.

A special handpiece with an extremely small head by virtue of integrating the head of the revision file with the pinion gear of the handpiece reflects today's clinicians' desire for instruments aiding more rapid root canal retreatment.

In addition to the heated end in system-B (Sybron-Endo, Orange, CA, USA) and similar devices, ultrasonic files have a firm place in the retreatment of root canals. The variety of ultrasonic tips available has grown in recent years, from extremely fine K files for the removal of broken instruments to special tips for the removal of gutta-percha and cement.

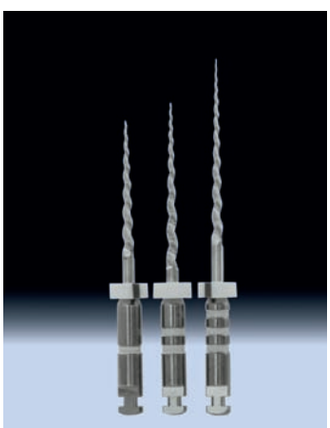


15.4 Post removal using ultrasonics

In this case, a screw pin was loosened preoperatively using an ultrasonic device and subsequently successfully removed by counterclockwise rotation.

15.5 Handpiece for retreatment

The R-Endo-System (MICRO-MEGA, France) has a distinct design—InGeT (integrated gear technology)—in which the pinion gear of the handpiece has been integrated with the engaging head of the file. This approach required a file head of only 7.5 mm (regular height is 14.5 mm), which means the handpiece head is extremely small. The reinstrumentation files have a tip diameter of size 25 and a taper of 12%, 8%, 6%, or 4%.



15.6 Endomotor and NiTi files

The very first endodontic motor with a special program for use with NiTi files for reinstrumentation of root canal fillings was the Endostepper (S.E.T., Munich, Germany).

Left: Specially shaped NiTi files for reinstrumentation (ProTaper Universal D1-D3, Dentsply Maillefer, Switzerland).

Root Canal Treatment

C

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16 Rubber Dam

The legacy of the dentist Sanford C. Barnum was founded on March 15, 1864, when he punched a hole in a sheet of rubber and stretched it over a mandibular molar. That day represented the beginning of the dental rubber dam—a term long used in the construction and shipbuilding industry for the isolation of a cavity from moisture. Decades later, with the development of improved suction techniques, the rubber dam became less important in the field of dentistry. However, the isolation of a tooth with a rubber dam to achieve a totally dry field of work remains an absolute clinical requirement for endodontic treatment. The European Society of Endodontics (ESE) guidelines (2006) give the following reasons for use of the rubber dam:

- prevention of salivary and bacterial contamination;
- elimination of the risk of aspiration and swallowing of instruments;
- prevention of spillage of irrigating solutions into the oral cavity.

There are a few exceptions to these basic requirements, but they seldom occur in daily practice.

Unfortunately, even today there is debate about the purpose and clinical rationale behind the preparation of a dry field using a rubber dam. The arguments *against* using a rubber dam are many: It takes too long to apply; patients do not readily accept it; patients become nervous and are irritated by it; it is no longer a "contemporary" dental device; endodontic treatment can be performed quite well without the rubber dam; etc. However, all the reasons for not using the rubber dam are not able to withstand critical evaluation. Studies such as those by Stewardson and McHugh (2002) clearly demonstrate that the vast majority of patients readily accept the use of a rubber dam, independent of age, gender, type of dental treatment, time of application, length of the appointment, or position of the dam.

In 1908, the veritable "grandfather" of dentistry, Dr. G. V. Black, wrote in his book *Operative Dentistry*: "probably no other technique, instrument or treatment in dentistry had been more universally accepted and advocated, and yet is so universally ignored by practicing dentists. Many reasons can be given but in most cases the fundamental cause is inadequate explanation and training in the dental schools. If any operative technique is not clearly taught and seen to be efficiently executed by the teachers, the new members of the dental profession will not use it willingly."

European universities have accepted this tenet, and reports indicate, for example, that 91.6% of all German dental schools routinely use rubber dam for dental treatment (Baumgartner, 2003). However, 15 years ago, only 5% of surveyed dentists in Germany used the rubber dam, and 65% never used it (Winkler, 1991). In a 1997 study by Maier, 17.5% of German dentists regularly used the rubber dam. Most recent studies in Germany indicate that 8.2% of dental practitioners routinely use rubber dam, and an additional 25.3% use it in more than half of cases (Baumgartner, 2003).

From an international perspective, the USA is at the top: 59% of general dentists and 92% of endodontists reported that they always use rubber dam (Whitten et al., 1996). In contrast, 31% of Swiss dentists reported regular use of rubber dam, but 69% never used it (Barbakow et al., 1995). In Great Britain, 60% of dentists never used the rubber dam (Whitworth et al., 2000), and in Belgium 64.5% never used it (Hommez et al., 2003).

It has long been acknowledged that root canal treatment must be carried out under sterile conditions, because bacteria are always the cause of endodontic disease or its progression (Kakehashi et al., 1965; Sjögren et al., 1997). Keeping in mind these scientific facts and clinical practicalities, the rubber dam remains a simple, quickly applicable, and effective tool in endodontics.

The Rubber Dam

A 15 × 15 cm (6 × 6 in) sheet of rubber is the most frequently used rubber dam for clinical use. The raw material—as with latex gloves—is the sap of the native rubber tree. Chemically, the substance is a cis-1.4 polyisoprene. The material is available in five different thicknesses; in endodontics the medium, strong, and extra strong sheets are most commonly used.

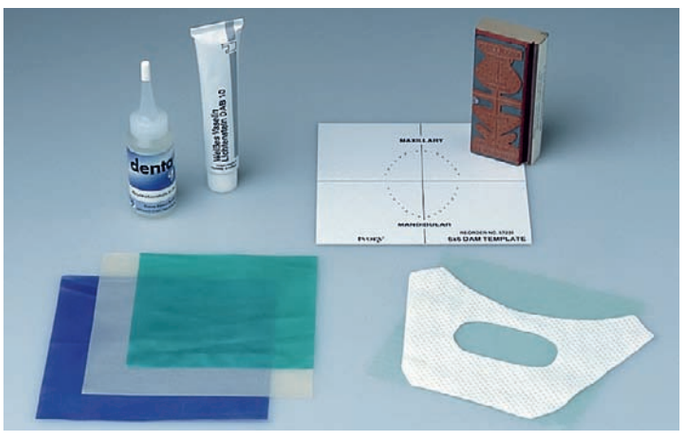
Because latex allergies are quite commonly encountered, and have been observed during endodontic procedures (Chin et al., 2004), various manufacturers do provide either artificial latex (Isodam Non-latex) or latex-free rubber dam material (Flexidam Non-latex).

During endodontic treatment procedures, usually only a single tooth at a time is isolated, and so just one hole, positioned slightly off-center in the rubber dam sheet, is often all that is required. If additional teeth or groups of teeth need to be isolated, templates are available for orientation of the holes. The Ivory rubber dam punch is the instrument of choice for making appropriate holes in the rubber dam for clinical application. Although the use of special lubricants, Vaseline, or even shaving soap has been proposed, patient comfort is most easily ensured by using lip balm or placing a soft cloth barrier between the rubber dam sheet and the face/lips.

16.1 Basic rubber dam armamentarium

Latex rubber is available in various thicknesses and colors. The size is usually approx. 13 x13 cm (5 × 5 in) (green) or approx. 15 x 15 cm (6 × 6 in) (blue, cream). The cloth napkin prevents direct contact between the rubber sheet and the skin. Most recently, silicone rubber dam sheets (light green, Roeko) have become available for patients with latex allergy.

Use of lubricating agents (Dentaglide, Sigma Dental) or Vaseline makes application of the rubber dam easier. Templates simplify positioning of the hole punch in the sheet.



16.2 Rubber dam punches

The Ainsworth punch (left), with a hinge located behind the punch plate, has remained unchanged for almost 100 years, and offers the ability to make perforations in five different sizes.

The Ivory punch (right) is the best instrument for punching the rubber dam. Because of its design it is possible to punch a hole much further toward the center of the rubber dam sheet. The hinge is positioned in front of the punch plate, which permits almost perpendicular and therefore exact punching.

16.3 Punching

Left: Close-up view of the Ivory rubber dam punch showing the movable punch plate with six hole sizes ranging from 1mm to 2 mm.

Right: Making a single hole off center in one of the four quadrants (approximately 4–5 cm from the edge) simplifies placement of the rubber dam in all four quadrants: The material is turned to the left or to the right to use the hole for a maxillary or mandibular tooth. This also permits the assistant to dispense with a template and punch the holes identically for all regions.

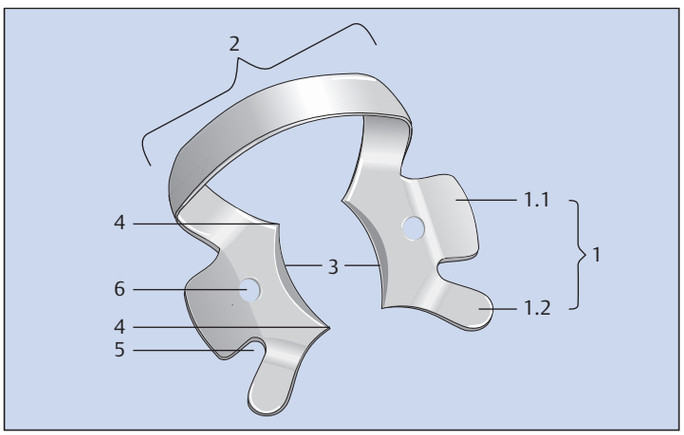
Rubber Dam Clamps

In the earliest configurations of the rubber dam, the sheet was held in place with wooden wedges or dental floss. Soon a myriad of clamps became available designed for use on individual teeth or groups of teeth. Today, stainless-steel clamps are the most commonly used, but plastic is also available.

The rubber dam clamp needs to engage the tooth at certain critical contact points. The clamp is meant primarily for retention of the rubber dam, which it does through its spring action below the height of contour of a tooth. It may also help to slightly retract the gingiva. Currently, the following rubber clamp types are universally recognized:

- normal clamp (with wings);
- wingless clamp;
- distal clamp;
- anterior tooth, premolar, and molar clamps;
- cervical or labial clamps;
- retention clamps (for retention of the rubber dam sheet);
- retraction clamps (for gingival retraction, e.g., Brinker tissue retractor, Schultz clamps).

An exception is clamp size 212, which provides both retention and retraction.



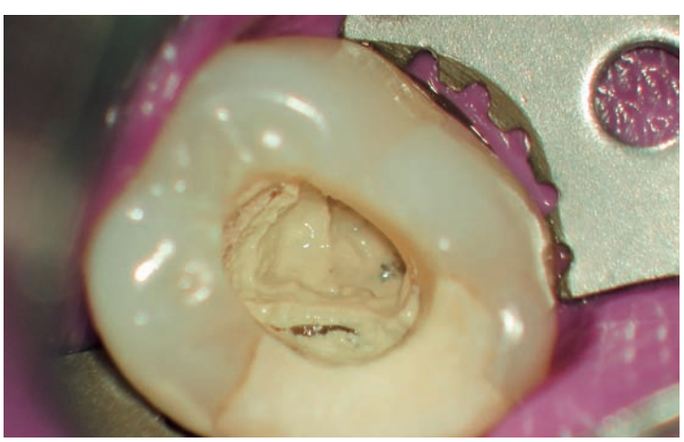
16.4 Parts of a rubber dam clamp

1 Clamp wings (lingual and buccal) with:
  1.1 Central arm
  1.2 Anterior arm
2 Clamp bow (distal)
3 Clamp beaks
4 Contact points
5 Notch
6 Clamp holes

16.5 Clamp selection

As there are numerous manufacturers providing many different types of rubber dam clamp, the selection process is not always easy. Clamp sets can help in orientation. The selection portrayed here, from Ivory, consists of eight types:

8A Molar (also for broken down crowns)
14A Molar, partially erupted
8 Maxillary molars
7 Mandibular molars
212 Anterior teeth
0 Premolars (high bow)
1 Premolars
2 Mandibular premolars



16.6 "Tiger clamp"

Recently, Ivory has developed rubber dam clamps with serrated beaks. These are called tiger clamps and provide excellent retention. In general, rubber dam clamps should have a matte finish, especially when performing endodontics with a clinical microscope, because the light reflection may make intraoral photography more difficult.

Pretreatment Preparation

Once the practitioner has selected the appropriate rubber dam and clamp, the clamp forceps helps in placement of the dam. The Ivory forceps are associated with the least amount of gingival trauma.

The extraoral rubber dam frame is available in a variety of shapes and sizes. Some dentists prefer plastic frames because they are radiolucent and the rubber dam does not have to be removed while taking intraoperative radiographs. However, plastic rubber dam frames are damaged by the autoclave process over time, resulting in eventual fracture and an unesthetic appearance.

If metal frames are used, the patient's eyes and skin should be protected by having plastic caps on both ends of the frame. For ease of application, it is beneficial if the dental assistant routinely prepares a complete rubber dam tray. For retention, Wedjets (Naturlatex [Collène Whaledent, Ohio, USA]) and dental floss, and also composite resins, dental cements, or impression compound (e.g., Kerr [Orange, CA, USA]) should be available. For complete sealing of the properly positioned rubber dam apparatus, it may be necessary to use Cavit (ESPE, Seefeld, Germany) or a periodontal dressing.

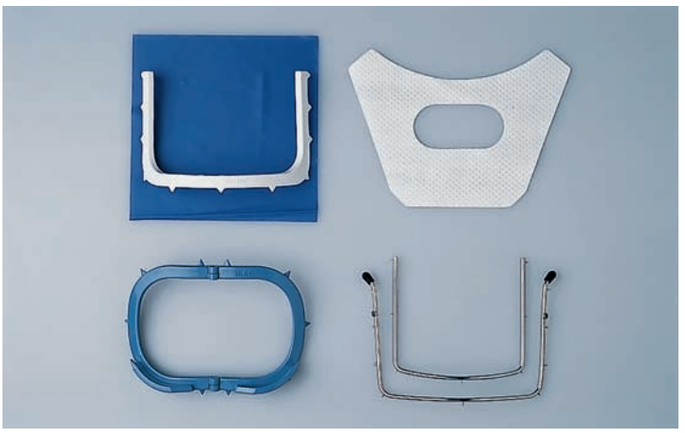
16.7 Rubber dam forceps

The Ivory rubber dam clamp forceps have withstood the test of time. A steel spring behind the hinge and a steel clasp permit solid and secure positioning at any given degree of opening. The working end has a double bend, which simplifies insertion into the oral cavity.

Right: Only the Ivory forceps have retention teeth that keep firm hold of the clamp even when the clinician exerts a gingivally directed force on the clamp; because of the teeth, the tips of the forceps do not slip through the clamp holes, thus preventing gingival damage.

16.8 Rubber dam frames

Many frames for rubber dam application are U-shaped, with the bottom of the "U" resting on the patient's chin and the open ends oriented toward the nose. Included in the figure are plastic frames (upper left) and radiographically visible metal frames, e.g., Young (below right), in sizes of 5 and 6 in (12.7 and 15.24 cm resp.). A more recent development is the folding frame (Sauveur; below left), which incorporates a hinge for opening and closing the frame to permit introduction of intraoral radiographic film packets in the patient's mouth.



16.9 Assembled rubber dam tray

The assembly by a dental assistant of a prepared tray simplifies and accelerates the placement of a rubber dam. A prepunched rubber dam, frame, clamp forceps, and the appropriate clamp, as well as a hemostat, are placed on the tray, ready for use.

Right: Additional aids for the stabilization of the rubber dam include Wedjets (rubber bands in various thicknesses dispensed from a commercially available device), dental floss, wooden wedges, or Kerr impression compound.

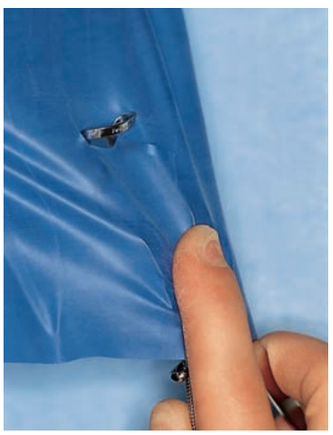
Applying the Rubber Dam

There are various methods of applying the rubber dam. Four common application techniques are presented here. In general, it is wise to consider various factors before attempting the application procedure.

- If the clamp is placed in the rubber dam sheet before insertion into the mouth, there is no need to use a dental floss sling to prevent inadvertent swallowing of the clamp.
- Application of the rubber dam sheet after it is affixed to the frame helps to achieve symmetric mounting more easily and also reduces application time.

Rubber Dam Application: I (Bow Technique)

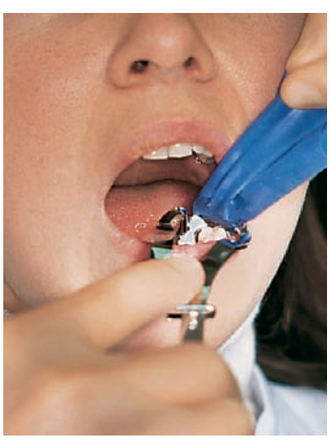
The bow technique of rubber dam application can easily be carried out by one person if the instructions detailed below are followed. In addition, it is advantageous to have excellent vision of the oral cavity when placing the rubber dam clamp. A disadvantage of this method is that the rubber dam sheet must be subsequently stretched over the clamp wings, which can result in tearing. To prevent this happening, it is wise to use the largest punch diameter. The rubber dam frame is positioned and affixed only after the dam and the clamp are secure.

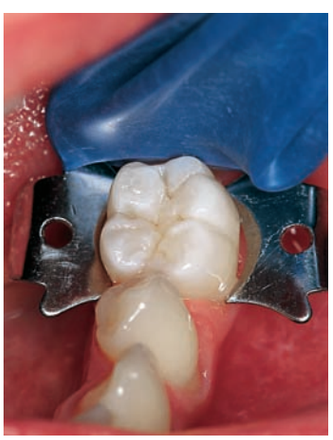


16.10 The "bow technique"

Left: Using the index finger, the rubber dam is forced onto the rubber dam forceps at the level of the hinge. The rubber is then stretched with the other hand over the bow; using the retention teeth of the forceps the rubber is also stretched over the clamp.

Right: The punch through the rubber dam is completely stretched over the clamp bow of the clamp and the rubber is folded over to permit easier handling.





16.11 Application: step 1

Left: The rubber dam, clamp, and forceps are inserted into the oral cavity.

Middle: The clamp is secured on the tooth. This application technique provides excellent visual access, making it easy to locate the tooth to be treated.

Right: The rubber dam is stretched buccally over the central wing.

16.12 Application: step 2

Left: The buccal wing is completely exposed.

Right: The rubber dam will have achieved its final position when the material is stretched over the lingual wing.

Rubber Dam Application: II (Wing Technique)

A widely practiced method of applying the rubber dam is to insert the central arms of both the lingual and the buccal wings of the clamp into the punched hole in the rubber dam, hence the name "wing technique." It is regarded as the simplest method (Winkler, 1991), and permits unilateral application.

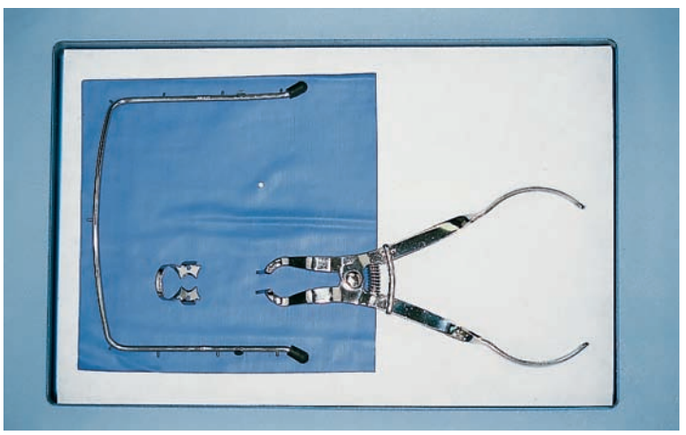
The procedure has two steps:

1. Preparation of the complete assembly by the dental assistant before the treatment begins.
2. Application of the fully prepared rubber dam assembly into the patient's mouth.

In anticipation of the procedure, it is necessary to have a tray set out with all necessary instruments. The dental assistant should place the selected clamp into the rubber dam sheet at an angle of 45°, with the bow positioned distally with regard to the dental arch in which the tooth to be treated is located. Then the rubber dam frame is attached; diagonal stretching is helpful and practicable. In addition, the subsequent positioning of the dam should be done in such a way as to create two pockets at the lower border to catch the overflow of fluids during the instrumentation procedure.

16.13 Tray assembly for the wing technique

A prepunched rubber dam, clamp size 7 (Ivory) for mandibular molars, a Young frame (approx. 15 x 15 cm [6 × 6 in]) and the Ivory rubber dam clamp forceps ready for application.



16.14 Preparation: step 1

Left: The clamp is held with the forceps. The index finger rests upon the forceps hinge.

Middle: The punched rubber dam sheet is stretched over both wings of the clamp.

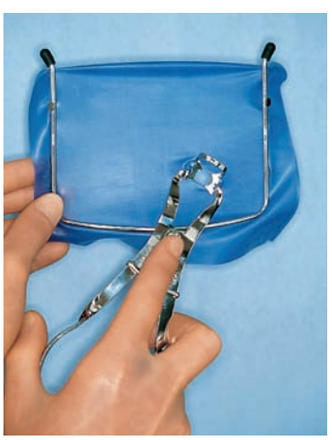
Right: The sheet is then stretched diagonally from one of the upper ends of the Young frame to the opposite lower end of the frame.

16.15 Preparation: step 2

Left: The rubber dam is stretched across all ends of the frame and should extend somewhat beyond the base of the frame.

Middle: The lower overhang is used to create left and right pockets, that is, the sheet is turned inward from both sides and the lower portion is pulled over the upper edge.

Right: The patient holding the preformed cloth napkin.



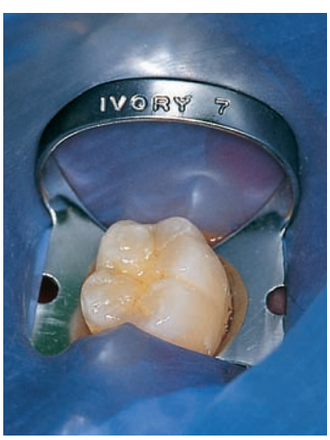
If the unit consisting of the rubber dam clamp, clamp forceps, rubber dam sheet, and rubber dam frame is preassembled, the time of application in the patient's mouth is reduced to a minimum.

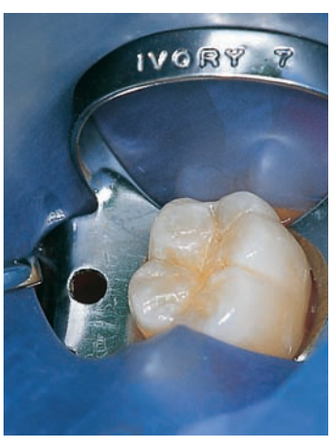
Disadvantages of the wing technique include reduced vision when placing the assembly in the mouth and the necessity for force application against the resistance offered by the rubber dam sheet when the clamp has to be placed in the posterior segment of the dental arch. It is also necessary to avoid injury ("pinching") to the soft tissues in the vicinity, such as the tongue, lips, or cheek. While the clamp is being placed below the height of contour of the tooth, the patient should report any pinching of the gingival tissues. The application is completed by stretching the rubber dam sheet over the clamp wings using a spatula, followed by proximal adaptation with dental floss.

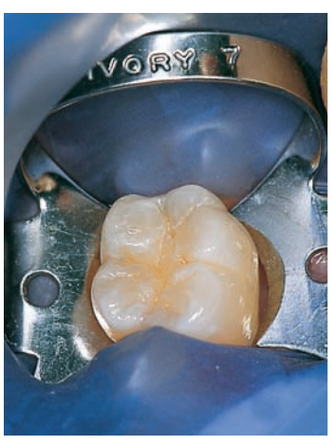
With the help of the technique described here, many clinical situations can be mastered. This rubber dam application technique should become part of the standard repertoire of every dental practice.

16.16 Application: step 1

The preassembled rubber dam sheet, frame, clamp forceps, and the clamp are inserted into the patient's mouth. By spreading the beaks of the clamp, the tooth to be treated can be visualized and localized.







16.17 Application: step 2

Left: The clamp has been positioned on tooth 36 and the forceps removed.

Middle: A spatula is useful for stretching the rubber over the lingual wing of the clamp.

Right: The spatula is also used to stretch the rubber over the buccal wing.

16.18 Application: step 3

Using dental floss, the rubber dam is forced gingivally both mesially and distally into the proximal undercuts, thus completing the circular adaptation of the dam to the tooth.

Middle: The rubber dam is fully in place. The beaks of the clamp contact the tooth in the cervical region on both the buccal and lingual sides.

Right: Extraoral view of the rubber dam with the cloth napkin in place and the pouch for placement of the saliva ejector.

Rubber Dam Application: III (Rubber Dam Sheet First)

As with other methods of rubber dam application described here, this technique can also be enhanced by preassembly by the dental assistant, providing a tray with forceps, clamp, and rubber dam in the appropriate configuration. In the case depicted below, the foldable frame (Sauveur) provides a space at its left and right lower borders to accommodate the saliva ejector.

The first step is a try-in of the selected clamp. Once it sits well and is positioned appropriately, the rubber dam material is stretched onto the frame and then placed in the mouth; the fingers are used to force the rubber dam around the tooth to be treated and which is just under the punched hole in the sheet. This procedure has several advantages.

- The rubber dam immediately inhibits any aspiration or swallowing of instruments or materials.
- Although some clamps—such as the double bow 212—only permit positioning of the rubber dam after clamp placement, most other clamp types can be used with this technique.

A potential disadvantage is the impingement on soft tissues, which can be very difficult with molar teeth and uncomfortable for the patient if the rubber dam sheet has to be forced in the direction of the floor of the mouth or against the cheek.

16.19 Tray assembly for the "rubber technique"

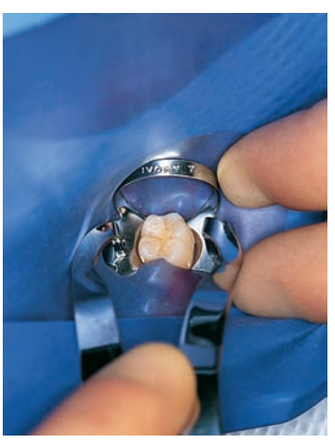
Left: The rubber dam has been punched in the region of tooth 36 and mounted on the hinged Sauveur frame, including the suction napkin. Molar clamp size 7 is already positioned in the forceps.

Right: The components consisting of the rubber dam and frame are shown in place in front of the patient. The saliva ejector (below left) has been inserted from the right side.

16.20 Application: step 1

Left: The rubber dam sheet is positioned over tooth 36. The punched hole is stretched open using the fingers of the left and right hands and stretched over the tooth crown.

Right: The forceps with the clamp is inserted into the mouth and the clamp is carefully placed at the cervical region of the molar. The clamp should always contact the tooth and not the rubber dam.



16.21 Application: step 2

Left: Using dental floss, the rubber dam is forced beneath the contact points proximally.

Right: The rubber dam and rubber dam clamp in their definitive positions.

Rubber Dam Application: IV (Clamp First)

In this last technique, first the rubber dam clamp is placed on the tooth and appropriately adjusted. Similar to application III, all of the elements—clamp, clamp forceps, rubber dam material, and rubber dam frame—should be preassembled. Only the sequence of placement is reversed.

A key point in this procedure is to make sure that the clamp will not be "lost" into the oropharynx. This can be done by looping a sufficient length of dental floss around the bow of the clamp and letting it hang outside the mouth within easy reach, thus ensuring that the clamp can be quickly removed if necessary.

One difficulty that may be encountered with this technique is that when placing the rubber dam the hole in the sheet must be stretched widely to position it over the appropriate clamp. The use of wingless clamps is recommended, as their smaller dimensions will reduce the risk of tearing of the dam. A particular advantage of the clamp first technique is ease of visibility while placing the clamp on the tooth.

Regardless of the technique used, the next step is always disinfection of the operative field, and in the dental situation chlorhexidine is the agent of choice.

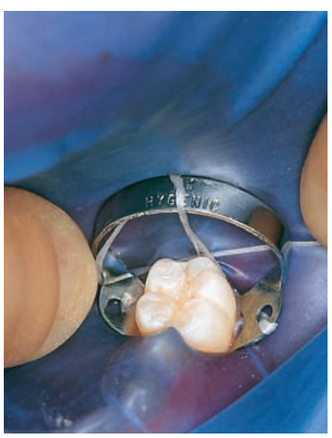
16.22 Clamp technique

A wingless clamp (Hygenic B1) has been placed directly on tooth 36. Note the dental floss looped on the clamp to protect against possible aspiration. The clamp is placed using forceps to carefully position the beaks at the cervical margins of the tooth at the level of the gingival margin; finally the forceps are slowly released to reduce the tension in the clamp for definitive placement.

16.23 Rubber dam frame placement

Left: The rubber dam sheet has been placed on the hinged Sauveur frame. The sheet is stretched across the left and right sides at the bottom edge of the frame to form a pocket that is completely sealed against fluids. The depicted hinged frame has a groove for guiding and retaining the saliva ejector.

Right: The rubber dam is then stretched over the clamp bow.



16.24 Securing the rubber dam

Left: The fingers are used to stretch the rubber dam over the lingual wing.

Right: Finally the rubber dam is inserted into the proximal undercuts using dental floss.

Special Cases

In some cases it may be necessary to modify the selected technique to ensure a well-placed and impervious rubber dam. The usual aids in this regard include dental floss, Wedjets, Kerr compound, or even the use of a second clamp. In addition, several materials have been specially designed for this purpose, including composite materials such as LC Block-out resin and OraSeal (Ultradent, South Jordan, UT, USA); these provide rapid and secure sealing to prevent leakage around the tooth to be treated.

Pretreatment planning and preparation will simplify the procedure. Even in patients with fixed orthodontic appliances, application of the rubber dam is possible.

Prosthetically treated teeth also often require endodontic treatment. For single teeth, it is often prudent to remove the crown to achieve better vision. Because the tooth requiring endodontic treatment is often broken down, the rubber dam may need to be fixed on an adjacent tooth; in the case of severely broken down teeth the use of a second clamp may be required.

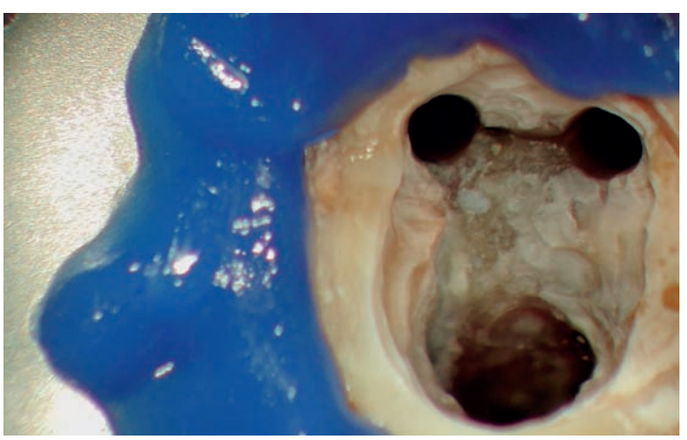
When taking radiographs during endodontic treatment, it is often necessary to detach part of the dam from the rubber dam frame. The hinged design of the Sauveur folding frame presents an elegant solution to this problem.

16.25 Application of the rubber dam in a patient with orthodontic braces

Despite brackets, wires, tooth crowding and multiple rotations the rubber dam was placed and secured by a clamp on the canine and a dental floss ligature on the premolar.

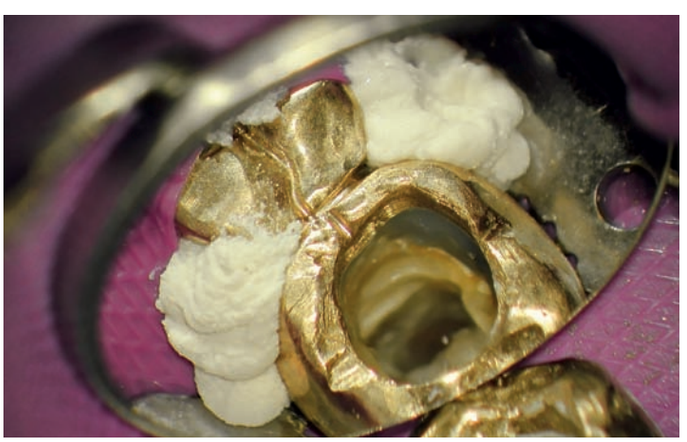
16.26 Sealing: I

A seal was prepared around a severely carious mandibular molar using LC Block-out (blue) and a rubber dam clamp.



16.27 Sealing: II

OraSeal provides a quick and effective means to prevent leakage following placement of the rubber dam.



17 Access Cavity Preparation

Root canal treatment begins with preparation of the access cavity, which should always be carried out with the rubber dam in situ. Difficulties encountered during instrumentation of a root canal can usually be traced to insufficient access cavity preparation and the lack of straight-line access to the root canals.

The entrance (orifice) of the root canal must be directly visible. This can often be facilitated by the use of loupes or a dental microscope. It is important to remove as much enamel and dentin as necessary. On the one hand, the access cavity must never be that small so as to inhibit visual detection of the root canal orifices. On the other hand, excessive preparation will reduce the structural strength of the remaining tooth tissues and hence the resistance to fracture (Reeh et al. 1983).

Errors made during the preparation of the access cavity usually result in a series of problems during the rest of the endodontic procedure. Such errors include insufficient excavation of caries as well as insufficient removal of the softened and unsupported hard tissues of the tooth. Incomplete removal of inadequate or poorly sealed restorations or crowns will lead to salivary and bacterial contamination of the instrumented root canal, which further leads to postoperative inflammation and other clinical consequences and ultimately failure. A lack of straight-line access to the root canals from within the pulp chamber can lead to ledge formation within a curved root canal and lateral perforation.

Therefore, a thorough knowledge of dental and root canal anatomy is of paramount importance when planning the shape and extent of the access cavity, because it must provide a complete view of the pulp chamber without compromising the tooth structure.

If previous restorations appear to be intact and do not show any inadequate areas on the radiographs, they can be left undisturbed. On the other hand, one must keep in mind that only after compete removal of an old restoration or a crown can the extent of carious penetration as well as poorly sealed areas be determined, the root canal orifices more easily detected, and straight-line access for root canal instrumentation guaranteed.

Build-up Restorations

Within a comprehensive treatment plan, only teeth with a favorable prognosis and which can be successfully restored should be included. Once the old restorations have been removed it is necessary to provide interim restorations, so that there is a stable coronal reference point for determination of endodontic working length and also to protect the tooth from overloading and possible fracture between endodontic appointments (Gutmann et al., 1991). In addition, it is necessary to ensure a seal against the oral milieu to prevent salivary contamination of the root canal.

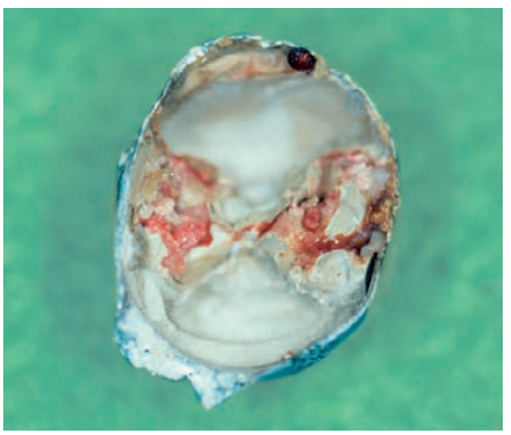
The extent of the enamel or dentin defect and the amount of time the interim restoration has to be in place, as well as the expected masticatory loads on the tooth, will determine the type of interim restoration. Glass ionomer cements show very good marginal adaptation early on, but continued occlusal forces soon lead to substance loss, compromising the restoration margins (Krejci et al., 1986).

Today, a resin composite adhesive build-up restoration is often the interim restoration of choice. The long-term marginal seal, resistance to masticatory forces, and color stability of modern composites are so good that the preendodontic build-up can often serve as the postendodontic definitive restoration or as a secure base for definitive prosthetic reconstruction.

17.1 Inadequate temporary restoration

Left: Tooth 26 was treated 6 months previously. Beneath the temporary restoration is an inadequately opened pulp chamber with dentin overhangs as well as considerably large areas with caries in place.

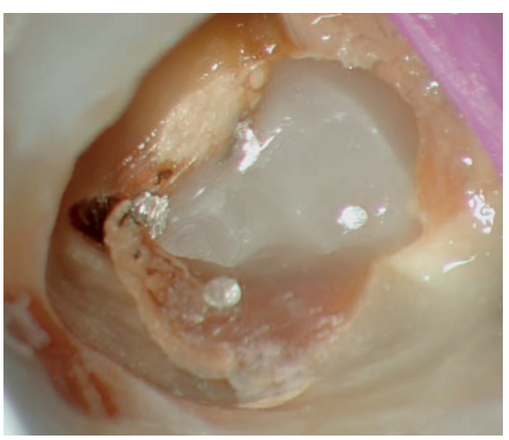
Right: The inside surface of the temporary, prefabricated crown contains some cement as well as impacted food remnants. The margins of the crown were not adapted to the tooth, and where thus being exposed to the oral environment.

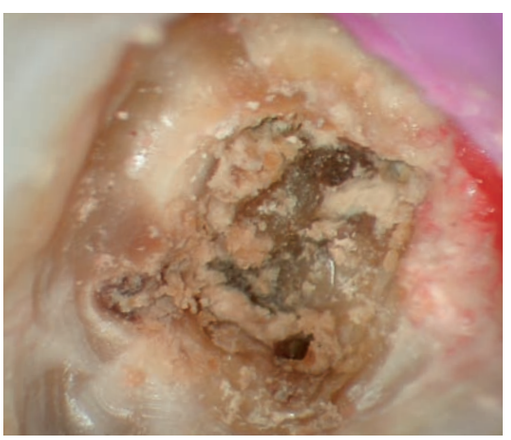


17.2 Initial opening

Left: This maxillary molar with four silver cones had to be re-treated. On re-opening the pulp cavity there were large areas of caries.

Right: Following successful removal of all four silver cones, the extent of the secondary caries became apparent.

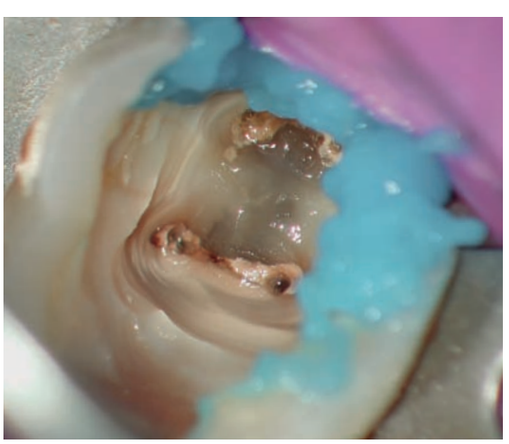


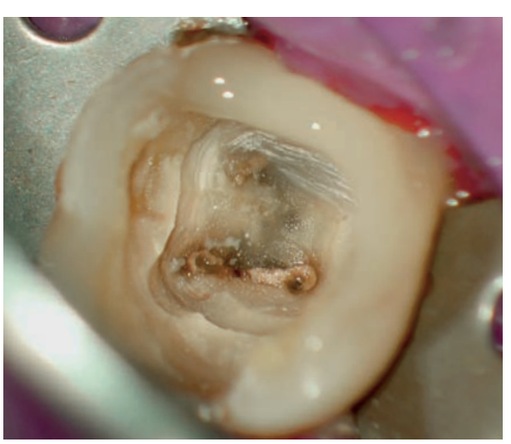


17.3 Build-up restoration

Left: Following complete removal of all carious dentin, the mesial cavity wall was etched with phosphoric acid.

Right: Using a flowable composite resin material, the mesial wall was restored, providing protection against salivary contamination.





Temporary Restoration

If the endodontic treatment procedure cannot be completed at a single sitting, an interim temporary restoration of the tooth will be required.

Cavit (3M Espe; zinc oxide, zinc, and calcium sulfate, glycol, etc.) is the most frequently used temporary filling material (Vail and Steffel, 2006) for both anterior teeth (54%) and posterior teeth (48%). Other agents commonly employed are IRM ([intermediate restoration material] 20% vs. 27%) and Cavit G (13% vs. 11%), which is usually used for inlays and is softer than Cavit.

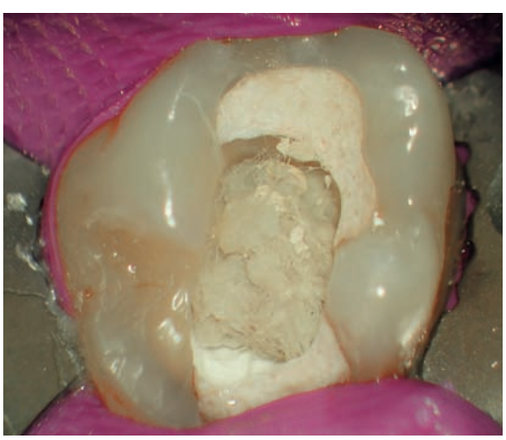
It is interesting that about 80% of all surveyed endodontic specialists reported that they placed a cotton pellet under the temporary cavity seal (Dillard et al., 2002; Vail and Steffel, 2006). Sixteen percent placed no other material beneath the temporary filling, while 1% reported using foam/sponge (Vail and Steffel, 2006).

However, research has clearly demonstrated that the presence of even a few (one to five) cotton fibers leads to a marked reduction in closure/seal afforded by the temporary restoration (Newcomb et al., 2001). Furthermore, the minimum layer thickness of 3.5 mm required for adequate sealing (Webber et al., 1978) will not be achieved.

17.4 Leaving the pulp chamber open

Left: Tooth 36 had been treated over a period of several months and mostly closed with a temporary restoration between sittings, but also left open if the patient experienced pain. At the initial sitting, a large amount of food debris was present in the pulp chamber.

Right: After cleaning up the pulp chamber and initial preparatory measures to have an adequate access cavity it became apparent that the pulpal roof was still partially intact. The distobuccal cusp was undermined by caries and had collapsed.



17.5 Preparation—Ledermix—Cotton—Cavit

Left: The almost universally accepted standard method for temporary endodontic restorations often leads to failure of the temporary cavity restoration because the minimal thickness for a temporary restoration of 4 mm cannot be achieved and Cavit can only withstand occlusal forces for 2–3 weeks.

Right: Placing paper points within the root canal and cotton pellets in the pulp chamber before placing the temporary restoration are for the most part counterproductive.

17.6 Failure of a temporary restoration

Left: In this molar, shortly after the initial treatment sitting including access cavity preparation as well as caries excavation and temporary closure with Cavit, a longitudinal fracture occurred. The cause was probably an initially existing in-line fracture and the preparation of the endodontic access cavity.

Right: Glass ionomer cement is often the material of choice for temporary closure of an access cavity. In the long term, however, this often leads to marginal imperfections and leakage.

Opening the Pulp Chamber

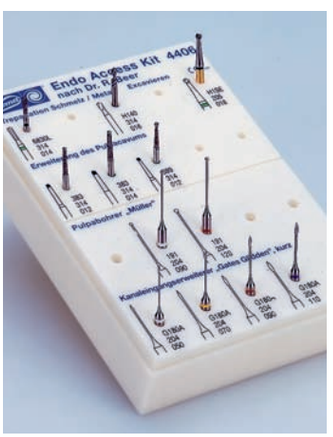
A potential major problem during opening of the pulp chamber, in addition to insufficient access preparation, is an incorrect estimation of the angle between the crown and the root. This error makes it much more difficult to locate the root canal orifices, and this can often be avoided with the use of a diagnostic radiograph. In teeth with large restorations, a bitewing radiograph should also be taken. To prevent excessive preparation at or perforation of the floor of the pulp chamber, the required length of the diamond bur can be assessed on a radiograph.

In addition to the classic diamond burs (round or cylindrical), combination shapes have been introduced, such as the Endo Access Bur (Dentsply, Maillefer) or the stainless-steel EndoZ. Because in many cases metal or porcelain/ceramic restorations must be drilled through during access cavity preparation, special burs may be required. Within a comprehensive endodontic instrument set, the practitioner should readily find the ideal instruments for a variety of approaches. With the increasing use of the clinical microscope, special designs such as the pulp bur "Müller" (Komet Brasseler, Savannah, GA, USA) incorporating a long delicate shaft are particularly useful.

17.7 Access cavity preparation and removal of old restorations

Left: Round burs as well as cylindrical burs, such as the EndoZ or the Endo Access Bur (Entsply Maillefer), are available worldwide for use in access cavity preparation.

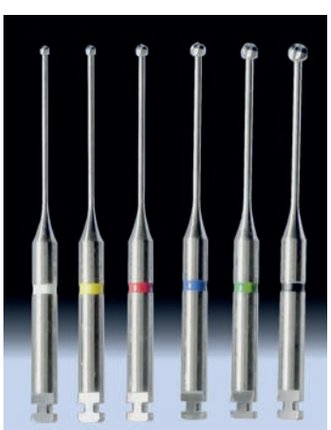
Right: Special burs for the removal of amalgam (Komet Brasseler, Savannah, GA, USA). Metal and ceramic and composite burs (from left to right respectively) are available for extending the cavity opening.



17.8 Instrument sets for access cavity preparation

As in other areas of dentistry, instrument sets for endodontics are commercially available. This makes the clinician's selection easier, combining well-known instruments with additional aids within a well-organized tray (here: Sybron Endo, Orange, CA, USA).

Right: The Endo Access Kit (Komet Brasseler) has diamond burs, round burs, Müller burs, and Gates-Glidden burs.



17.9 Aids for pulp chamber access

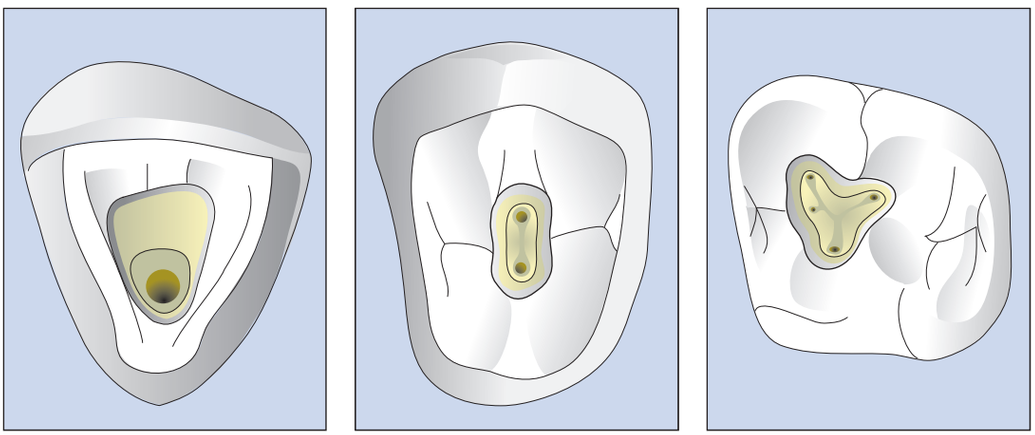
Left: The pulpal burs (Müller) combine a working end similar to a round bur with an especially long and elegant shaft. This provides excellent vision, even when working under the clinical microscope.

Right: The Gates-Glidden drills continue to be used effectively for drilling of the root canal orifices even after 100 years. The sizes start from 50 (= 0.5 mm) to 70, 90, and 110, and up to 130 and 150 (1.5 mm).

The shape of the endodontic access cavity should correspond to the shape of the roof of the pulp chamber. For *maxillary incisors* the shape is triangular and the cavity is positioned in the center of the palatal surface. The access cavity must be sufficiently extended to completely expose the pulp horns and permit removal of all pulpal tissue remnants to avoid subsequent staining or discoloration of the clinical crown.

Traditionally, the pulp chamber is opened at a 45° angle to the long axis of the tooth. This procedure, however, can easily lead to perforation at the cervical margin on the labial side. *Mandibular incisors* often show an anatomic variation that requires locating the pulp chamber opening almost at the incisal edge to achieve straight-line access to the root canal (Sonntag et al., 2006). Because of the small size of these teeth, this procedure can lead to perforation, or even to failure to identify the root canal orifice.

Access cavities in *premolars* should have an oval shape with the long axis directed buccolingually. In *maxillary molars*, the cavity is located in the central fossa with the bur inclined toward the mesiopalatal cusp because here the chamber is the widest. In the *mandibular molars*, the access cavity should have a trapezoidal shape and the bur should be directed somewhat distally, thus preserving the distal third of the occlusal surface.

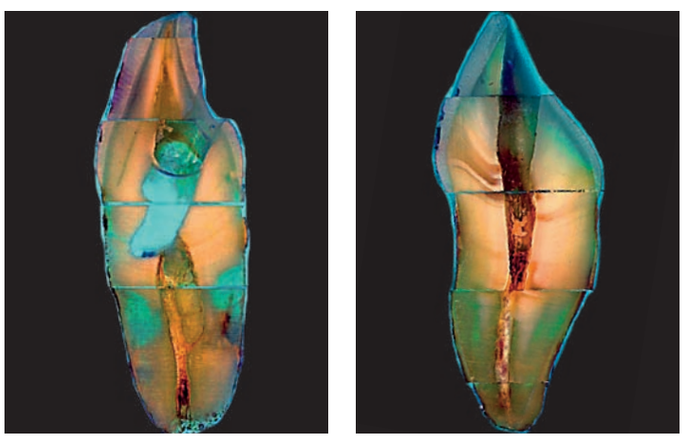


17.10 Access cavity preparation in maxillary teeth

Left: In anterior teeth the usually single root canal lies within the center of the tooth. Thus these teeth should be opened from the palatal aspect and the access cavity should be triangular in shape.

Middle: The opening for premolars is oval in shape in the buccolingual direction.

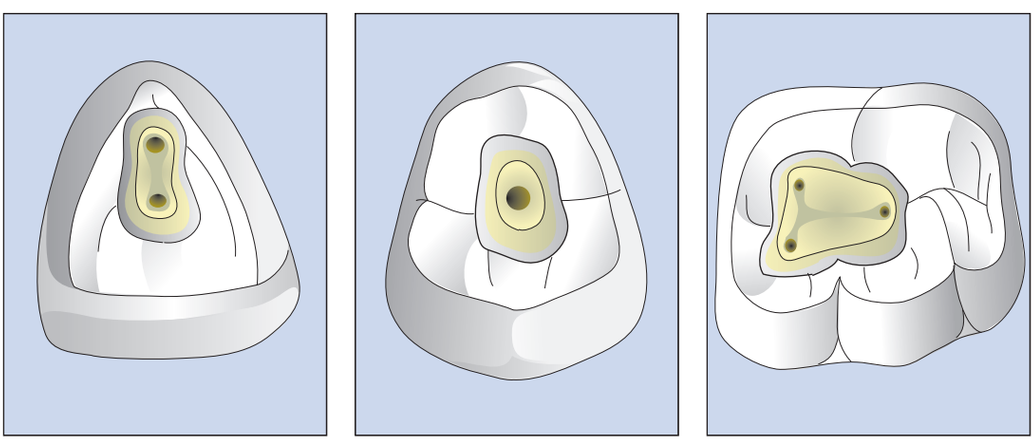
Right: The access cavity for maxillary molars is rhomboid or trapezoidal in shape. Note that several molars have a fourth root canal—the mesiopalatal root canal—in the mesiobuccal root.



17.11 Access cavities

Left: In most situations, anterior teeth, including the mandibular incisors, are opened for endodontic treatment in the middle of the lingual surface. Because of the inclination of these teeth, there is always a danger of perforation at the tooth cervix. The coronal pulp is also often not completely exposed.

Right: Straight-line access to the root canal is easier by drilling perpendicular to the lingual surface, but this often entails sacrifice of enamel at the incisal edge (courtesy of D. Sonntag).



17.12 Access cavity preparation in mandibular teeth

Left: Twenty-five percent of mandibular incisors and canines have two root canals. The access cavity from the lingual aspect is triangular in shape.

Middle: The access cavity in mandibular premolars is oval in the buccolingual direction.

Right: Mandibular molars should have a trapezoid-shaped access cavity, which should be somewhat wider mesially than distally.

Access Cavities

The preparation of an optimal access cavity is of great importance for successful endodontic treatment. Clinical failures such as perforations reduce the prognosis substantially; more obvious problems with canal preparation, such as ledge formation and perforation, are often the result of an inadequate access cavity.

To use rotary NiTi instruments effectively, a straight-line access to the middle third of the root is important to avoid curving of these instruments in the coronal aspect of the canal, which can lead to cyclic metal fatigue.

Current research clearly demonstrates that the structural weakening of the tooth during access cavity preparation is the most important factor in the increased susceptibility of endodontically treated teeth to fracture. For this reason, when creating the access cavity, dentin should be carefully and only selectively cut. Preoperative periapical and bitewing radiographs provide a quantitative assessment of the size of the pulp chamber and permit an appropriate selection of diamond or carbide steel burs.

The first stage in access cavity preparation involves the use of high-speed diamond burs with concomitant water cooling to penetrate the enamel and dentin in the direction of the largest dimension of the pulp chamber.

17.13 Diagnosis

Before preparation of the access cavity, orthoradial and bitewing radiographs can assist in the selection of the appropriately sized diamond and carbide burs. Clinically, the position of the rubber dam clamp often provides a good indication of the location of the pulp chamber.

Right: Rounded edge cylindrical diamond and EndoZ burs are frequently used to create the access cavity.

17.14 Location of the pulp chamber

A view from the lateral aspect permits assessment of the location and size of the pulp chamber; on the radiograph the hard tissues on the pulpal floor indicate the extent of the depth of the chamber.

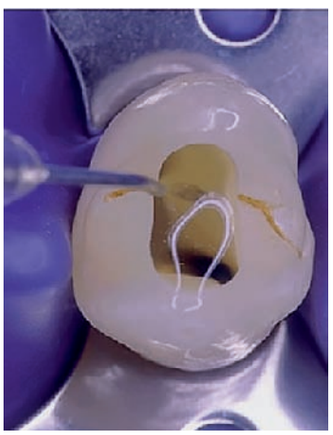
17.15 Preparation

Using a cylindrical diamond bur, the pulp chamber is opened in the direction of the greatest pulpal dimension, then a carbide bur (EndoZ, Dentsply Maillefer) is used to create a slightly diverging cavity while protecting the hard tissues of the tooth as much as possible. Note the staining of soft tissues with methylene blue.

Following the exposure of all the root canal orifices, the coronal third of each canal is widened. Following copious irrigation with sodium hypochlorite, the canal orifice is first engaged with an endodontic probe and then with a fine K file. However, this instrument should not at this stage be inserted into the canal to the expected working length. In this way, calcifications are removed and canal curvatures smoothened, and the apical penetration of smaller instruments is simplified.

This procedure permits a larger volume of the disinfecting solution to penetrate toward the apical region and ensures that the subsequent determination of actual working length is correct.

It is not uncommon to encounter pulp stones (ectopic dentinlike deposits) in the pulp chamber of a molar. Sometimes several pulp stones occur together, and they may be either loose within the connective tissue or attached to the pulpal floor; these must be removed to assure direct access to the root canals and prevent formation of niches for bacterial colonization. Often, pulp stones can be removed using a small excavator. Use of loupes and the clinical microscope, and also of ultrasonic tips, is recommended because these will protect the pulpal floor and reduce the risk of perforations.



17.16 Disinfection

An aseptic procedure is an important aspect of endodontic therapy. In addition, irrigating the pulp chamber with sodium hypochlorite provides the opportunity to remove residual soft-tissue debris.

17.17 Root canal orifices

Using an appropriate instrument, a pulp stone is removed from the floor of the cavity and washed out. Afterwards, the canal orifices can be probed and then the coronal third of the root canal can be instrumented with increasing sizes of Gates-Glidden drills.

17.18 Straight-line access

Rotary NiTi files, because of their flexibility, permit extensive instrumentation down to the middle third of the root canal. In most cases, the working length can be determined and achieved using K files of ISO sizes 10 and 15.

Detection and Identification of Root Canal Orifices

Following access cavity preparation, one must identify all the root canal orifices. Because of the hindrance to access caused by pulp stones, root canal obliteration, or previous endodontic treatment, this is often difficult. The spectrum of instruments has been significantly broadened in recent years: rotary NiTi files, ultrasonic files of various designs, hand files of sizes 6, 8, and 10 (also with handles for use with the clinical microscope), and NiTi files such as Mtwo (#10 .04) or the PathFiles (Dentsply Maillefer) with +13, #16 or #19 .02, which permit initial rotary instrumentation with file sizes from 15, even through the smallest canal orifices.

As important as these clinical aids, and adequate instrumentation, are, it is still the knowledge and clinical experience of the clinician that determines the correct identification and location of the usual number of canal orifices. One of the most frequent causes for endodontic failure is that a canal orifice and the canal itself were never even identified. In this regard, the clinical microscope has greatly broadened the scope of the previously accepted parameters. Ledges, narrowing, staining/discoloration, deepening and the finest structural/anatomic abnormalities can today be reliably detected, identified by means of color tests or the "bubble test," and subsequently successfully eliminated.

17.19 Widening the canal orifice

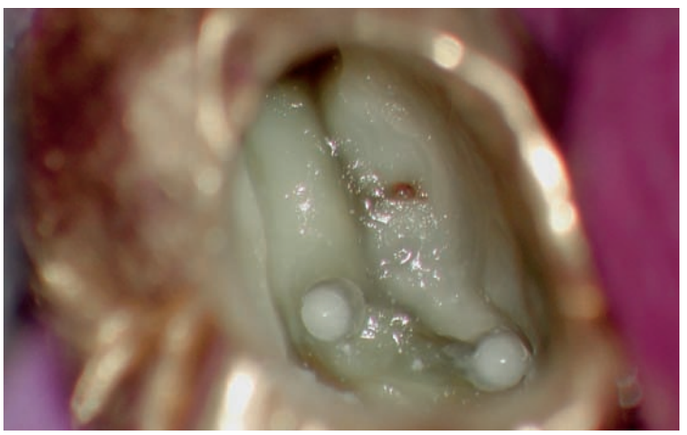
Left: Orifice shapers (Dentsply Maillefer) are NiTi files of sizes 20 (taper .05) to 80 (taper .08), which are used with a rotary motion to widen the canal orifice.

Right: Contemporary commercially available instruments include ultrasonic tips such as these two models with a zirconium nitride coating; these can be important aids in locating the canal orifices and removing calcified deposits.

17.20 Identifying the root canal orifices

After opening the pulp chamber of a maxillary molar, the orifice of the palatal canal is located using Gates-Glidden burs. At the bottom left of the image is the distobuccal canal and at the bottom right is the first mesiobuccal canal, both of which are filled with fluid. In the center note the red (blood) pinpoint—the entrance to the second mesiobuccal canal. The dark lines and grooves indicate the direction.

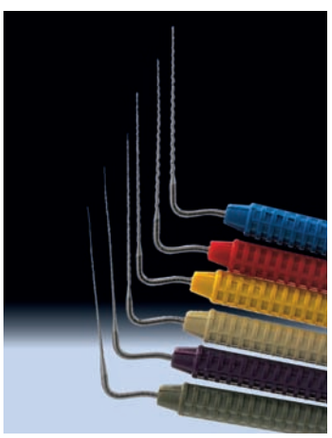
Right: Following irrigation with sodium hypochlorite, pus is oozing from one canal (arrow).

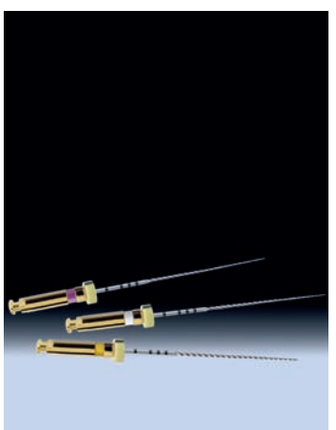


17.21 Probing and widening

Left: When using the clinical microscope and conventional hand instruments difficulties may arise because the field of vision is obstructed by the clinician's fingers. In this situation, use of instruments that are attached to a handpiece can be of benefit (MC files, VDW).

Right: Instruments with sizes 15, 16, or 19.02 can be used to advantage even in the tiniest of root canal orifices (courtesy of Dentsply Maillefer).

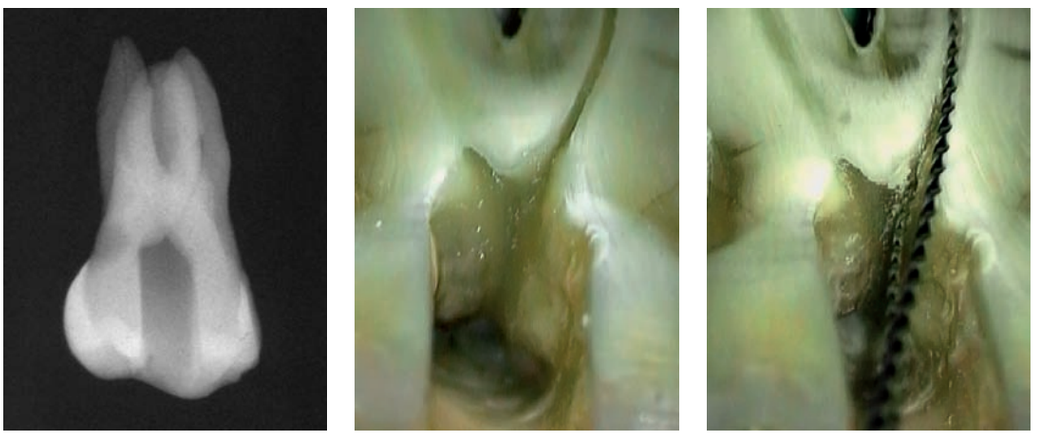




Straight-line Access

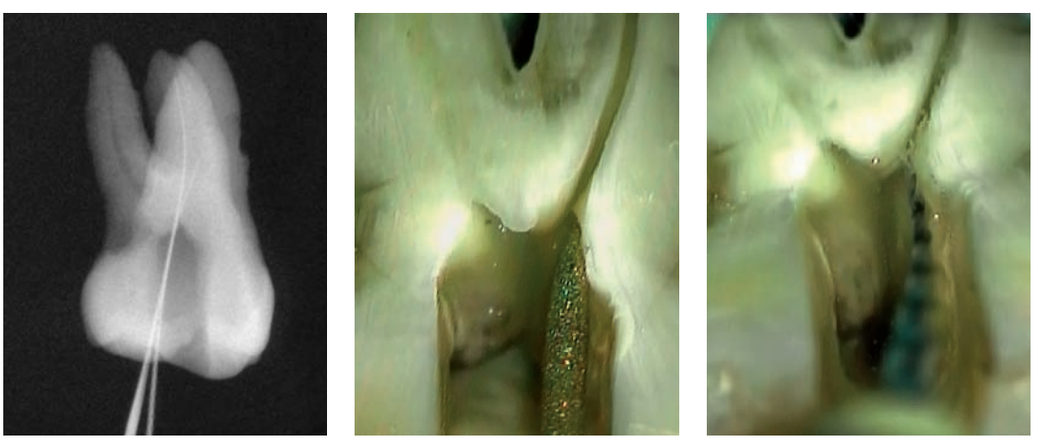
The access cavity should provide direct access to all root canals without significantly weakening the tooth crown. This is often extremely difficult in molars. In the maxillary molars, the mesiobuccal canals are often hard to find because their initial course is slightly mesial and then distinctly distal. In addition, the mb2 is often obscured by a dentin ledge that must be removed using rotary instruments or special ultrasonic tips. In the mandibular molars, the mesial root canals are usually more easily accessible but also often have a dentin ledge apically.

Straight-line access to the root canals can be achieved using rotary instruments such as a sequence of Gates-Glidden burs or special NiTi files. The use of Hedström (H) files has also been recommended, but this can result in over-preparation. It is also important to note that the improper use of Gates-Glidden burs can result in so-called strip perforations. For these reasons, these instruments should not be inserted deeper than 3–4 mm into the root canal. An actively cutting NiTi file can be introduced into the middle third of the root canal without the excessive removal of dentin near the furcation.



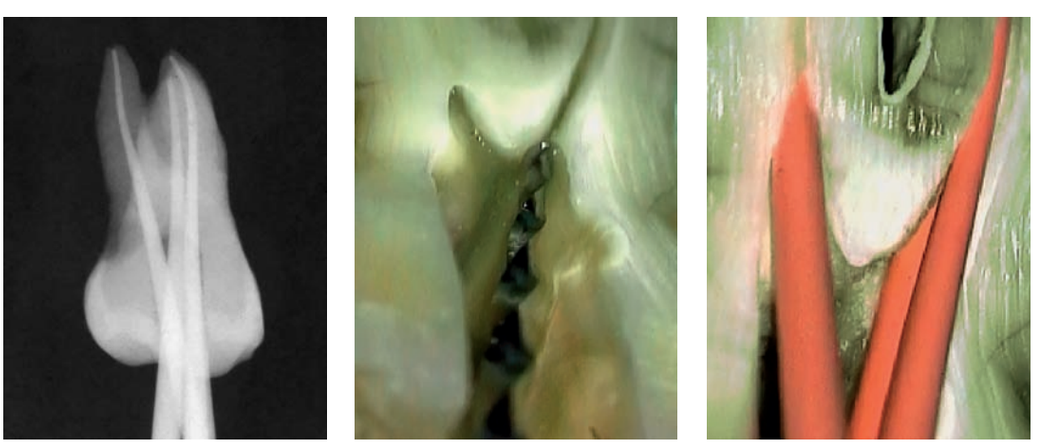
17.22 Maxillary molars

Both mesiobuccal canals in the maxillary molars course first mesially and then distally. In addition, the second, more palatally located canal, is often covered by a ledge of dentin.



17.23 Dentin ledge

Following identification of the root canal orifice, the dentin ledge is removed using an ultrasonic instrument in order to permit the introduction of a small K file a few millimeters into the root canal. Sufficiently large canal orifices permit the use of Gates-Glidden burs for enlargement.



17.24 Straight-line access

Using an actively cutting NiTi instrument, the canal orifice is widened and directed mesially. This permits the widening of the second mesiobuccal canal to an adequate size and determination of working length.

Note the straight-line canal course during the introduction of master points.

Obliterated Root Canal Orifices

Following penetration of the pulp chamber roof and preparation of the access cavity, obliterated root canal orifices are often encountered. This can be the result of formation of tertiary dentin or a host defense reaction to progressive caries, or it may represent the presence of a pulp stone. In such cases, careful study of a preoperative radiograph is often helpful and will lead to a successful clinical conclusion.

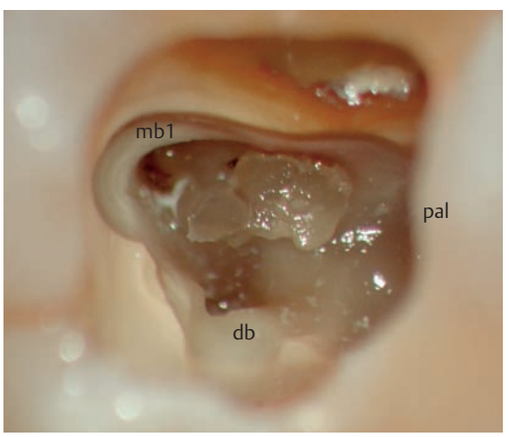
In addition, excess cement or build-up restorations as well as previously inadequate root canal fillings or post-and-core build-ups may render the detection of root canal orifices more difficult. Naturally occurring dentin overhangs or ledges must be removed beforehand. The anticipated root canal orifices are first entered using a stiff endodontic probe (e.g., the VA3 from Deppeler, Rolle, Switzerland), and then the guiding lines between the canal orifices are followed. In this regard, a visual aid is the use of methylene blue, which will also stain any fracture lines. The introduction of sodium hypochlorite or hydrogen peroxide will result in the release of oxygen bubbles, which is a sensitive indicator for closed or not yet discovered pulp canals.

Visual aids such as clinical loupes are also certainly useful, but it is the coaxial illumination and magnification with the clinical microscope that leads the way to clinical success.

17.25 Initial situation

Left: Following removal of the temporary restoration obvious extensive caries is visible on the mesial aspect of this molar. In the center a pulp stone is evident above the entrance of mb2. At the right margin of the photograph, the palatal canal orifice is visible.

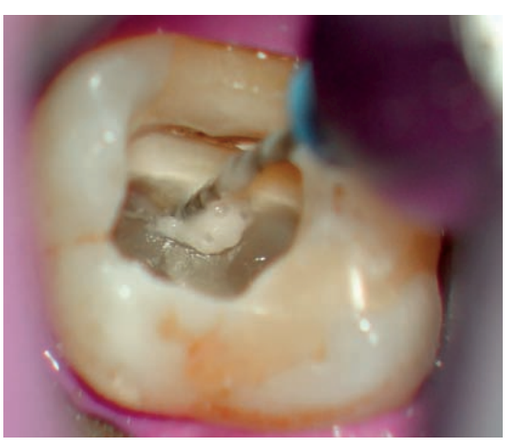
Right: The preoperative radiograph reveals a large mesio-occlusal restoration, and wide coronal pulp and severely curved buccal root canals.



17.26 Identifying the orifice of mb2

Left: Following removal of the pulp stone using an ultrasonic device, the very discreet orifice of mb2 can be located with a size 8 K file.

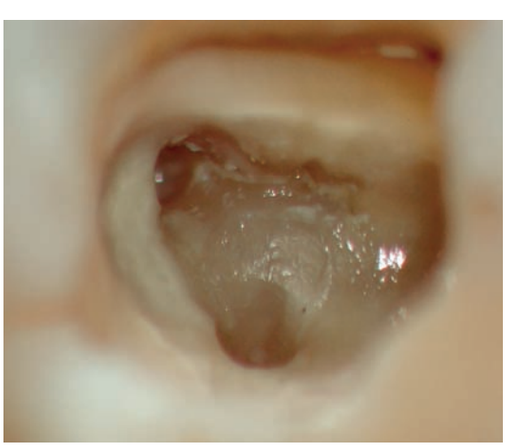
Right: Using a NiTi file, the canal orifice is widened.

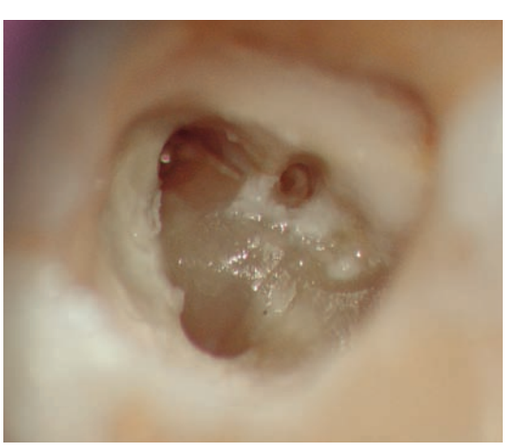


17.27 Widening the mb2 canal

Left: The mb1 and db canals have been widened using Gates-Glidden burs sizes 1–4, but the mb2 canal remains quite narrow.

Right: Additional rotary instrumentation of mb2 using NiTi files resulted in an obvious widening of the canal diameter.

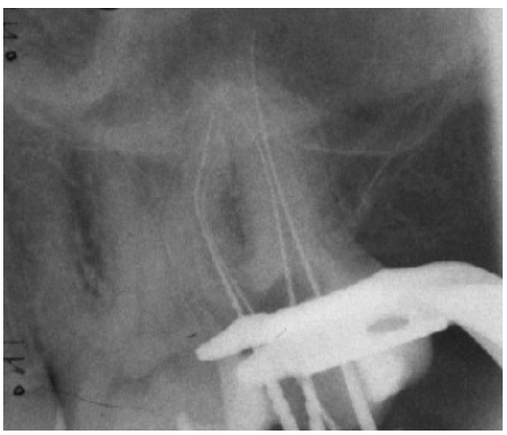


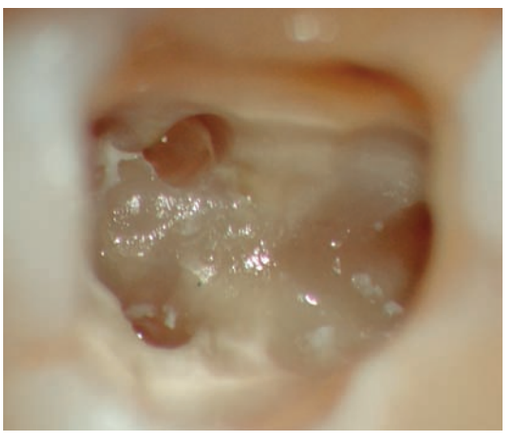


Using the clinical microscope, even very fine structures and root canal orifices become apparent. The commonly used size 15 file has a diameter of 150 µm at its tip and is obviously too large. The three other sizes, 6, 8, and 10, with diameters of 60–100 µm, are today an absolute must, whereby the MC file (VDW) or the Micro Opener (Dentsply Maillefer) allow adequate vision even with the microscope because of the configuration of their handles.

H files have a propensity to fracture and easily become stuck in the canal, therefore, K files are preferred in endodontics today. If there is binding of a K file in a root canal, it can usually be removed by the "watch-winding" method of instrumentation. Through slight forward–backward rotation, the K file removes dentin. The root canal is accessible for a few millimeters. Up and down movements will continue to widen the canal. If the clinician encounters resistance the procedure is reinitiated.

Conventional root canal files increase in diameter by 0.02 mm per millimeter. This results in frequent binding within the course of the canal while the tip of the file remains free. This is the reason for the classic millimeter-by-millimeter advance, supported by EDTA. Once a certain width is achieved it is possible today to proceed to NiTi files or the time-tested Gates-Glidden burs.

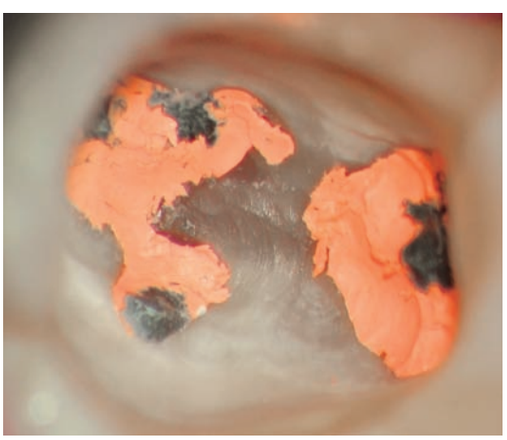




17.28 Finalizing the initial widening of the canal orifice

Left: The root canal length determination radiograph shows the four inserted files and very good length estimation following the principles of electronic apex location.

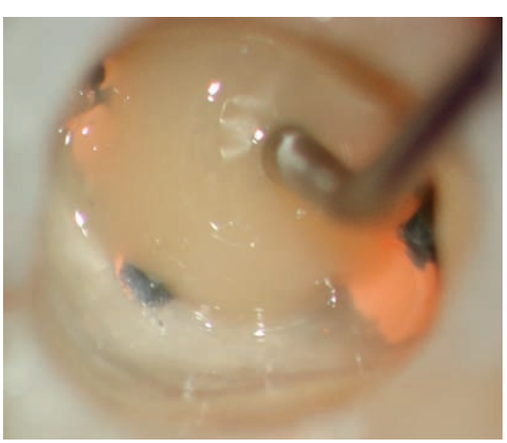
Right: The palatal canal was initially broad and open and was aligned using a Gates-Glidden size 5 bur within the first few millimeters (right). The mb2 (above left) became accessible for Gates-Glidden burs and was instrumented up to size 3 bur.



17.29 Conclusion of instrumentation

Left: Following precise electronic estimation of working length and radiographic determination, canal instrumentation is concluded. This clinical view depicts the fully instrumented three buccal canals. Between mb1 and mb2 is a fine line connecting the two canals (like an isthmus), which was not completely broached.

Right: Clinical view following insertion and cutting off the extra portions of the Thermafil obturator cones at the level of the root canal orifices.



17.30 Follow-up radiograph and definitive restoration

Left: The periapical radiograph shows the homogeneous and tapered shaped root canal fillings. The rather severe curves in the canals were excellently traversed and the root canal fillings terminated precisely at the apices of the canals.

Right: Following etching and application of bonding material to prevent coronal leakage, the floor of the pulp cavity was covered with a layer of flowable composite resin. It is important that this composite has a different color to permit any future detection of the root canal orifice.

Obliterated Root Canals

The capacity of pulp tissue to calcify is not limited to the odontoblastic layer. Fibrodentin deposits in the form of pulp stones can also be observed centrally within the pulp tissue, in both erupted as well as not yet erupted teeth, and in both the deciduous and permanent teeth in young or older individuals (James et al., 1959).

With increasing age, there is an evident increase in the formation of intrapulpal dentin, which causes the root canal to become ever narrower. This deposition of hard tissue within the pulp is usually the result of inflammatory processes.

With the exception of pulp stones with well-organized tubular dentin, which are secreted and formed by odontoblasts, atubular osteoid or lamellated dentinoid hard-tissue formations consist of fibrodentin. These structures are formed by distant pulpoblasts that are identical to the mesenchymal cells of the dental papilla (Baume, 1980). With regard to the genesis and classification of pulp stones, there are several different hypotheses. One is that as a result of external factors/stimulations, pulpal cells die and concentric calcified deposits form around these dead cells. Some have speculated that thermal irritation may also play a role (Gerstner, 1971).

17.31 Diagnostic radiograph

The distal bridge abutment, tooth 37, has an obvious periodontal–endodontic lesion. This preoperative radiograph shows significant periapical bone destruction, a vertical periodontal lesion, as well as horizontal bone loss of about 50%.

Within the mesial root, there is only a fine line representing the original root canal and this disappears completely for about 3–4 mm about 2 mm below the crown margin.

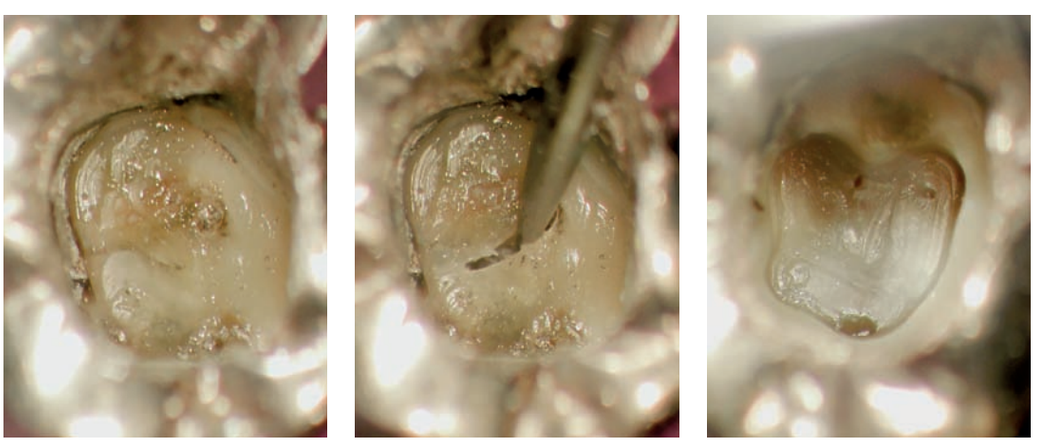
17.32 Initial cavity access

During the initial access preparation procedure one must proceed carefully into the pulp chamber in order to prevent perforation.

Left: Note the slivers of gold created by the drilling, which are visible on the pulpal chamber roof. On the lower right side of the photograph, a small root canal orifice is visible.

Middle: A dental probe is successful in exploring for and detecting a root canal orifice.

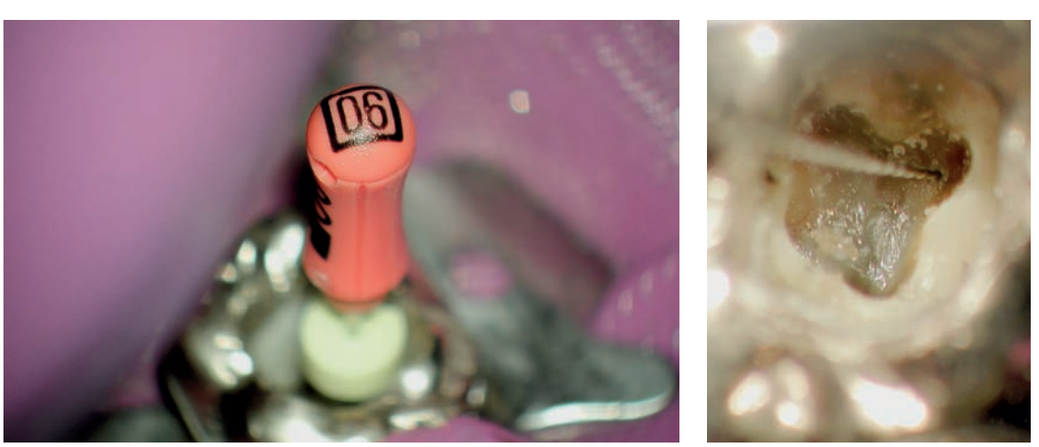
Right: Following removal of the entire pulp chamber roof, the floor of the pulp chamber becomes visible.



17.33 Detection of the root canal orifices

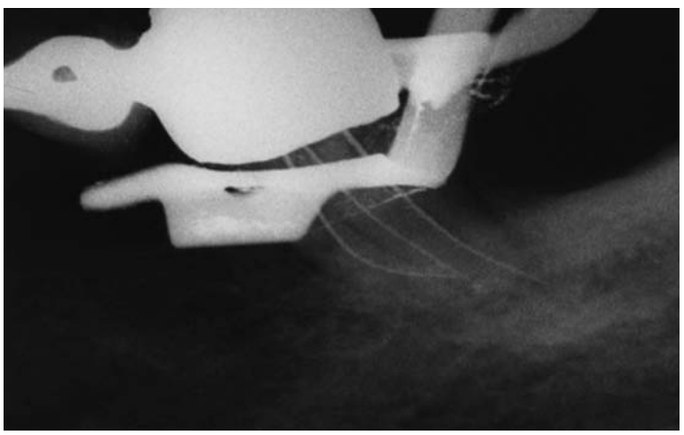
The initial size of the canals was so small that only the smallest size of K file (size 6) could penetrate into the canal orifice and identify its course.

Right: Initially, the size 6 K file could only penetrate a few millimeters into the mesiobuccal root canal.



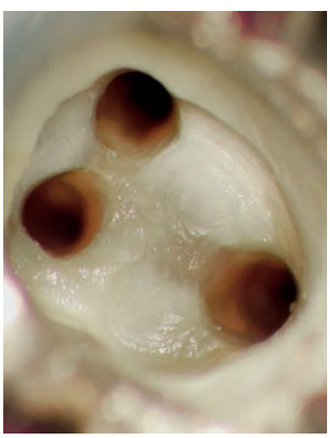
Diffuse mineral deposits within the root canal consist of amorphous calcium phosphate. These deposits are usually found along blood vessels or collagen fibers and can be observed even in clinically intact teeth. In carious teeth, however, there is a significant increase in intrapulpal mineralization (Seltzer et al., 1963). As a result of chronic inflammation, pulp stones and mineralized tissue deposits within the endodontium are the rule. With progressive caries, the extent of intrapulpal mineralization increases, and may lead to complete obliteration of the root canal (Beer et al., 1986).

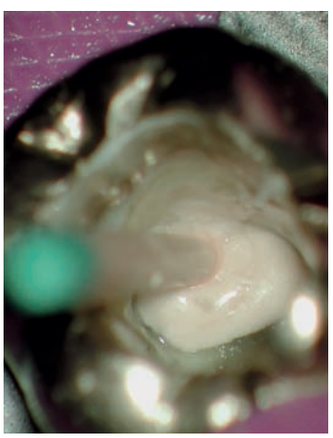
In their study of teeth with crown fractures, Cvek and Lundberg (1983) observed mineralization in 50% of cases, including both lamellated pulp stones as well as diffuse deposits of hard tissue. In 25% of the cases, inflammatory cells were demonstrated. In the age group of 10–20 years, pulpal mineral deposits were noted in only 8% of cases; however, in the carious teeth in the same age group the prevalence was 36%. In the age group 45–63 years, 90% of teeth showed calcified deposits. However, in radiographs, mineral deposits only greater than 200 µm can be clearly discerned (Tamse et al., 1982).

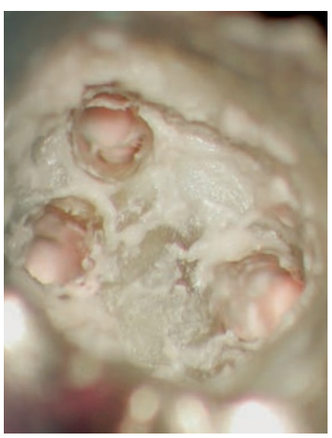


17.34 Radiograph for working length estimation

Following careful instrumentation and widening, all three root canals could be accessed to their full length. The definitive working length was determined by using an electronic apex locator, and finally an eccentric radiograph was taken.





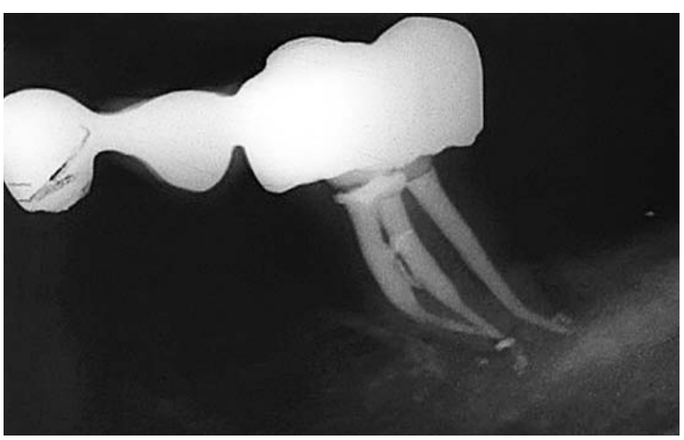


17.35 Filling the root canal

Left: Following root canal instrumentation, the three small root canals are widened and cleaned.

Middle: The root canal filling was carried out using Resilon, a synthetic replacement for gutta-percha. This photograph depicts the master point surrounded by the sealer.

Right: In this case, the heated vertical compaction method was used with the master point and a heated spreader was used for apical compaction. Apical seal was achieved using the down-pack technique.



17.36 Completed root canal filling

The thermoplastic root canal filling is depicted in the radiograph, which shows successful filling of even the smallest curves in the canals as well as the lateral canals. Both the mesial canals illustrate a complex system of intercommunicating canals.

Left: The excess Resilon root canal filling material is carefully severed off at the root canal orifice. The dentin is then etched in preparation for the application of a bonding material to prevent any coronal leakage.

18 The Dental Microscope in Endodontics

Owing to the very small size and complex nature of the tooth root canal system, the naked eye cannot discern in sufficient detail several factors that influence the outcome of endodontic treatment. Problems arising during primary root canal treatment, such as narrow root canal orifices, detection and dealing with obstructions or obliterated canals, and recognizing root canals type III or V–VII (Vertucci, 1984), can severely limit the chances for treatment success.

In addition, endodontic retreatment is usually associated with a myriad of problems that can be effectively overcome only with combined application of the underpinning clinical knowledge and state-of-the-art technology.

The introduction of the clinical dental microscope provided a new dimension in diagnosis and therapy in dentistry. The combination of additional light, magnification, and ergonomic design makes the dental microscope one of the most significant technological developments in endodontology. It permits the effective use of both time-tested techniques and newer therapeutic procedures, and has thus expanded the boundaries of endodontology to include successful maintenance of previously questionable teeth.

As early as 1921, Carl Olof Nylen used a monocular microscope during surgical therapy. In 1975, Baumann described the first use of a microscope in dental practice. He recommended it as a diagnostic and therapeutic aid during caries removal, root canal treatment, during the preparation of dental restorations, and calculus removal. He drew attention to its ergonomic construction, which allows the dentist to adopt an upright seated position during treatment. Following additional technical improvements during the early 1990s, the dental microscope is increasingly used in specialist dental practices.

The dental microscope provides for an optimal clinical diagnosis (Zaugg, 2004). The clinical detection of even the smallest root canal orifices is significantly improved using the dental microscope (Schwarze, 2003). The newest minimally invasive therapeutic procedures for the removal of endodontic pins/posts, root canal filling material, foreign bodies, and fragments in complex retreatment cases can be carried out successfully. In addition, new frontiers in endodontology have been opened up by the ability to deal with intracanalicular obstructions and ledges, and to close perforations successfully (Arnold, 2009).

Construction and Functions

Support Stands

There are three ways in which a dental microscope can be integrated into a dental operatory. In addition to the classic floor mount, wall-mounted or bench-mounted supports are available. Besides the need for an adequately strong supporting wall or countertop to support the device, key criteria for selection of the appropriate support include the space available and the desired degree of mobility. An absolute requirement is a vibration-free area when working at larger magnifications. Before finally purchasing, a technical inspection of the space by an expert is recommended.

Balance

Of special importance for the day-to-day, continuous use of the dental microscope is ease of mobility combined with a solid and stable support. The use of simpler, apparently cost-saving supports can lead to vibration/oscillation, delaying clinical treatment. It must be possible to manipulate the device with one hand in all planes of space, and so the mechanical or electromagnetic brakes must securely hold the microscope in the desired position.

18.1 The dental microscope

ProErgo, Zeiss (Oberkochen, Germany and Thornwood, NY, USA)

1 Floor stand
2 Swing arm with integrated computer controls and display monitor
3 Swing arm with integrated light source
4 Connection with electromagnetic brake
5 Optical head including:
– Eyepiece
– Tiltable tube
– Varioscope
– Video camera
6 Hand grips for:
– Light with brightness control
– Zoom, brake
– Documentation

Optics and Magnification

The optics of the dental microscope consist essentially of the Kepler tube (eyepiece and tube), the magnification changer, and the objective itself. The binocular optics permit spatial perception. The range of the focusing lens system varies according to manufacturer, especially at higher magnifications.

Formula to calculate magnification (M):

$$M_{total} = \frac{f\ tube}{f\ objective\ lens} \times \gamma \times M_{ocular}$$

f Focal length
γ Factor of magnification
M Magnification

Light

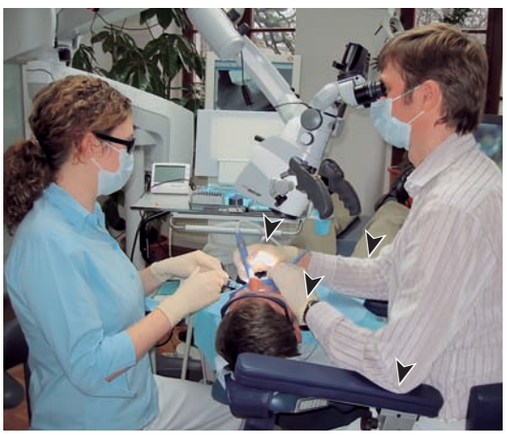
The light originates from a separate source and travels through a fiberoptic to the optical parts of the device, and via a prism, coaxial to the optical axis. The light source may be a halogen or xenon lamp. These lamps are significantly different in terms of heat development, color of the light, temperature, and lifespan.

For endodontic practice, the xenon light source is used, with a daylight-like color, temperature of about 5800 K and a significantly higher light intensity of 420 klx in contrast with halogen lighting (which is about 100 klx).

Ergonomics

The use of a dental microscope permits the clinician to assume an upright posture that is less prone to cause fatigue, at a distance of more than 50 cm from the patient. For the treatment of maxillary teeth, the operator should be in the 12-o'clock position and for the mandible at the 8–9-o'clock position with respect to the reclining patient. With the patient's mouth wide open, treatment can proceed under indirect vision using a rhodium-plated mirror. For lengthy procedures, the patient's head should be stabilized using adjustable or inflatable airline-type pillows.

For vibration-free clinical work at higher magnifications, use of an operator chair with arm supports is absolutely necessary. Extended arm rests and a back support will guarantee a comfortable and relaxed position for the back muscles of the clinician. At the same time the dental assistant can keep a check on the stage of the clinical procedure on the monitor, and therefore provide optimum assistance. Other aids include microprobes, microabrasive ultrasonic instruments, and microsuction. Procedures of more than 2 hours' duration can be easily carried out while continuing to maintain a high level of concentration.



18.2 Four-handed technique: I

Left: Lower jaw treatment: operator at the 9 o'clock position. The clinician has supports at four points (arrows). Co-observation by the dental assistant is made possible by computer monitors in the operatory. To prevent visual distraction related to the xenon lighting, wearing of protective glasses is recommended.

Right: Continuous irrigation and microsuction during root canal instrumentation.

18.3 Four-handed technique: II

Left: Without changing working position, the dental assistant can directly inspect the treatment area and follow the progress of intracanal procedures.

Right: Six-handed technique.
The distribution of tasks permits an uninterrupted view through the microscope and proceeding with the treatment without any loss of time, compared with the time-consuming instrument changes required with the hybrid techniques.

In order to achieve focused clinical work during endodontic treatment, visualization through the dental microscope should be interrupted as little as possible. Changes of instruments should occur according to well-practiced hand gestures between the assistant and the clinician, adhering to an established procedural sequence. The assistant should ensure that the required instruments are placed into the clinician's hand in the correct position. Endodontic procedures in the mandible are best carried out using the four-handed technique.

For maxillary endodontic treatment the six-handed technique has proven effective; the clinician should be at the 12-o'clock position with respect to the patient. An efficient distribution of tasks between two dental assistants permits a very focused and time-effective clinical sitting. Documentation, maximizing optimal visual access, suction, irrigation, and control of the overall field of operation should be the responsibility of the first dental assistant. The second dental assistant should maintain responsibility for rapid and secure instrument changes without the clinician having to take their eyes away from the microscope.

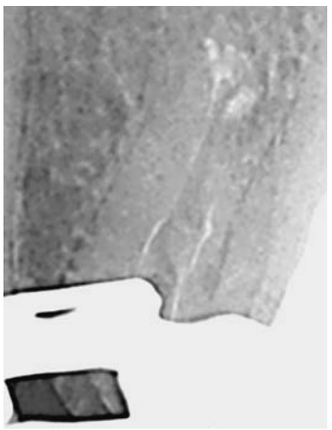
18.4 Apical correction

Tooth 12 has a lateral canal in the apical region and a buccally oriented perforation.

Left: The radiograph shows the adequate apical seal with MTA and gutta-percha.

Middle: Clinical view ×30 magnification.

Right: Radiographic view 6 months post operatively.



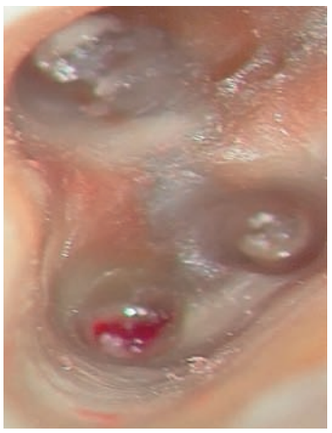
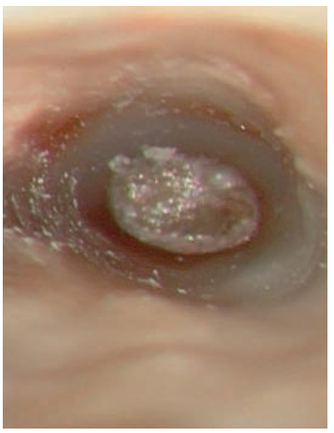
18.5 Complicated anatomy of a maxillary molar

Tooth 16 following failure of direct pulp capping.

Left: ×20 magnification: control of the correct apical seal.
mb1: Pain on probing, hemorrhage
mb2: Obliterated
db: Necrotic pulp

Middle: The palatal root canal has been obliterated by tertiary dentin formation into the middle third of the root canal.

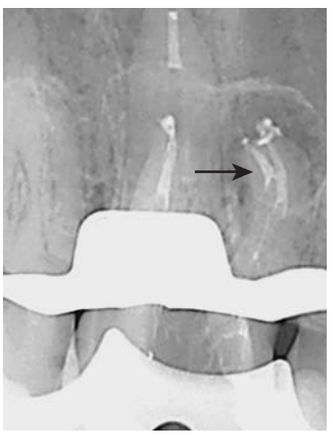
Right: Initial radiograph.

18.6 Down-pack

×20 magnification: Note the apically compacted gutta-percha.

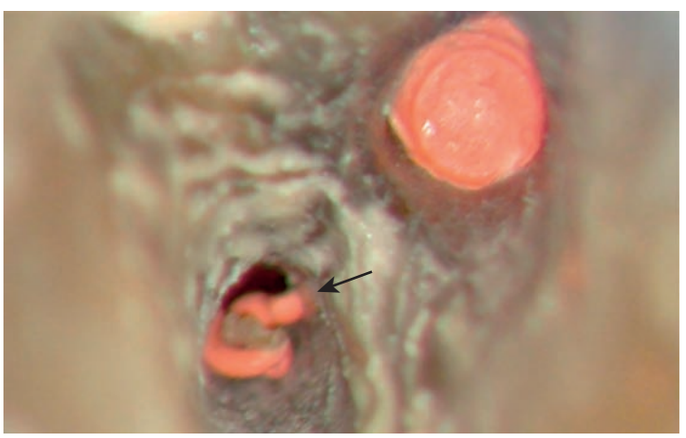
Right: Radiographic view. The arrow indicates the level of the clinical photograph.

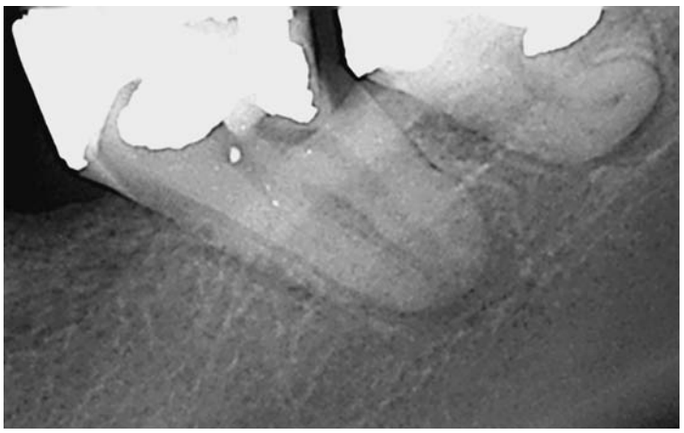


18.7 Backfill

The root canal filling in canal mb2 at ×20 magnification. Because of the thermoplastic compaction, a lateral canal was also filled with gutta-percha in the region of the adjacent mb1 (arrow).

Right: Radiographic view.

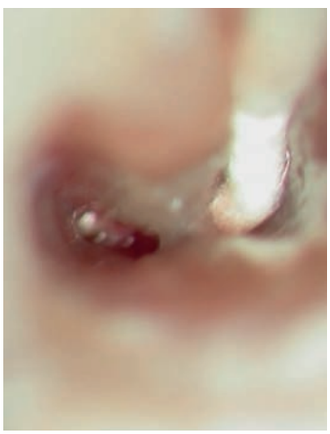




18.8 Complex mandibular molar

Radiograph of tooth 37 shows an extensive restoration with a deep carious defect on the mesial aspect.

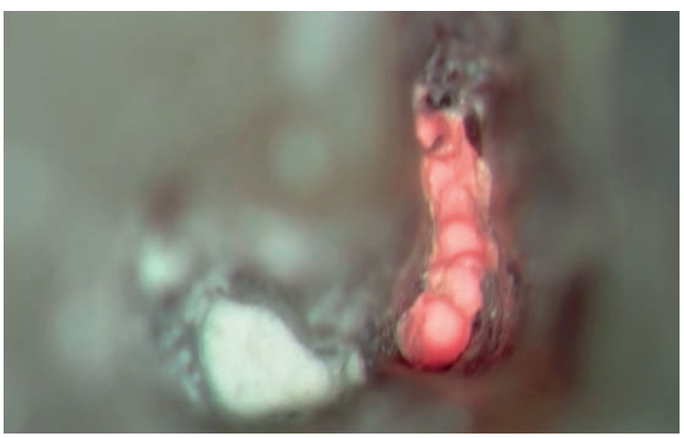
Left: Following initial opening of the pulp chamber, a C-shaped canal configuration is evident (×16 magnification).



18.9 Instrumentation under direct view

At ×30 magnification, inspection of the apical region reveals an oval and wide open canal on the distal aspect (>ISO 60).

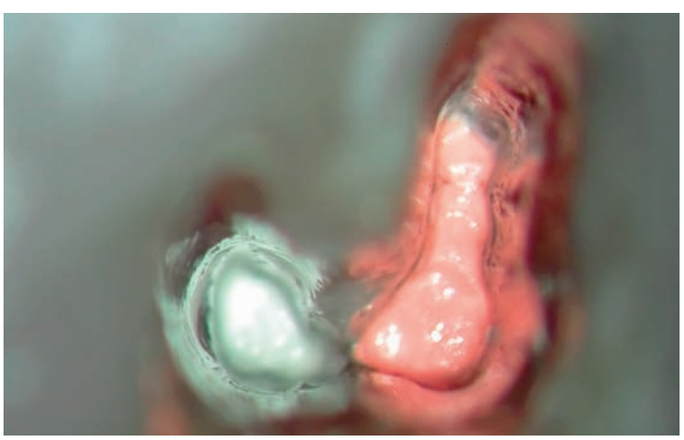
Left: Barrier of the mesial C-shaped canal with a paper point before application of MTA in the distal canal.



18.10 Down-pack

Clinical view of the apical seal (×30 magnification).

Left: Interim radiograph to assess the quality of the apical seal.



18.11 Backfill

View of the backfill before the adhesive build-up (×30 magnification).

Left: Radiographic view.

Advantages of the Dental Microscope

It is impossible to imagine modern endodontology without the use of a microscope. Currently about 500 dentists/endodontists in Germany and many thousands worldwide represent a large group of enthusiastic and by now well-experienced dentists who have adopted the triad "magnification, illumination, instrumentation."

Magnification is usually at a maximum of ×20–25; higher magnification reduces the resolution and limits the field of vision.

Illumination is usually with a xenon lamp, which provides excellent visibility with color characteristics similar to daylight. The special feature of the microscope is the coaxial illumination of the field of operation, i.e., the light is in the same axis as the line of sight of the clinician. This permits shadow-free illumination, which is not possible even when using binocular loupes with a miniaturized light source affixed between the eyes at the height of the glabella.

Canal instrumentation plays an ever increasingly important role because the working field is often obscured by conventional instruments.

18.12 Illumination

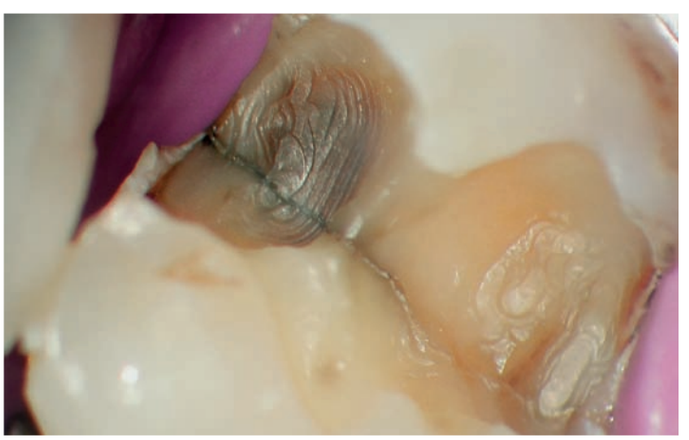
American endodontists—above all Dr. Syngcuk Kim from Philadelphia—have advocated the use of the clinical microscope in dentistry and point out the advantages of the triad: *Magnification—illumination—instrumentation.*

Left: The field of view of the OPMI ProMagis (Carl Zeiss, Oberkochen, Germany) clearly demonstrates the coaxial capability of the microscope.

Right: Clinical photograph of a molar that is clearly darker and more poorly detailed compared with the image in Fig. 18.13.

18.13 Magnification

Two important advantages of the clinical microscope are the variable and (in comparison to loupes) higher magnification and the excellent, shadow-free vision of the working field. At ×24 magnification, the infraction lines are clearly visible, as well as signs of the use of a diamond bur.



18.14 Instrumentation

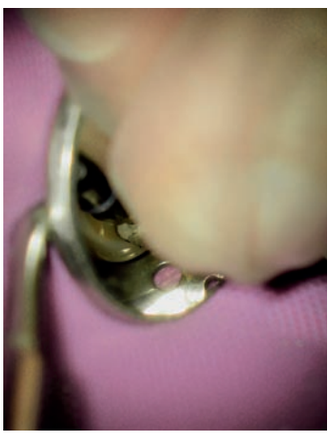
When working with a dental microscope, special instruments such as the handpiece-operated K files depicted here (Micro Opener, Dentsply Maillefer, Switzerland) are extremely important; the working field remains free of visual obstruction, and the clinician can detect and treat even the smallest root canal orifices.

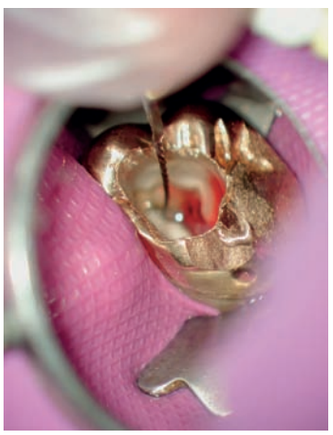
Magnification and Instrumentation

Magnification is a major advantage of the dental microscope in endodontics. However, this advantage can only be utilized if the view is not obstructed, which is indeed the case with many of the conventional endodontic instruments. For this reason, dentists using a dental microscope must learn to position the intraoral mirror appropriately and also to select endodontic instruments that are suitably delicate or used with a handpiece. In recent years, numerous specially designed instruments have become commercially available.

The early ultrasonic tips led the way and were initially designed for retrograde application, but then as more designs were developed, additional tips became available for the orthograde exploration of canal orifices and for dealing with calcifications and root canal obliteration.

In addition, extremely fine probes are now available with hand grips, ultrathin irrigating tips, pluggers and spreaders with hand grips, also made of titanium (because of its flexibility), as well as special instruments for the application of MTA (mineral trioxide aggregate) or heated gutta-percha.



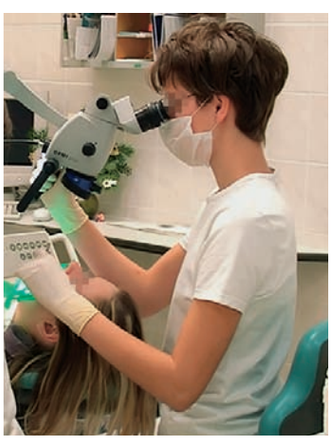


18.15 Visual obstructions

Left: While using traditional hand instruments, the operator's finger often obscures a large portion of the microscopic field.

Middle: The mirror must be positioned far enough away to prevent obstructing direct vision (right: below the rubber dam).

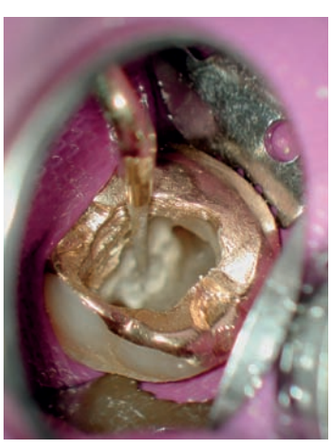
Right: The head of the handpiece is so large that it often completely obstructs direct vision.

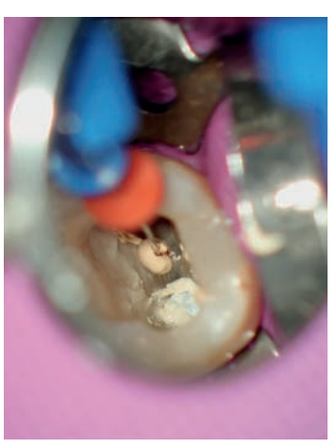


18.16 Use of the dental microscope

Left: A student during her first clinical endodontic treatment procedure in the initial endodontics course at the University Clinic of Dresden. Preparation of the access cavity and detection and widening of the root canal orifices up to the middle third of the root are carried out following exercise work under direct vision using the dental microscope.

Right: Rhodium-plated mirror for working under indirect vision with minimal loss of light and without double-vision (courtesy of www.eie2.com).





18.17 Special instruments

Left: Fine handpiece-operated K files such as the MC files (VDW, Germany) or the Micro opener (Dentsply Maillefer, Switzerland) permit excellent instrumentation and visualization.

Middle: The modern ultrasonic tips are also so delicate that the clinician has an excellent view beyond the instrument.

Right: Thin injection cannulas such as the Navitips (Ultradent, USA) also permit direct vision.

Selection of a Dental Microscope

The transition from general medical microscope to dental microscope is not yet complete. The specific needs of the dental situation, with regard to the use of a microscope in a dental or endodontic practice, are gradually being taken into consideration in newer models.

The main reasons for the routine use of a dental microscope include ease of handling and mobility. For integration of a microscope in daily dental practice, factors such as heat absorption and vibration in relation to the device's light source are of significance.

While sterile clinical/operative use of the microscope can be achieved using plastic covers, there are currently no practical procedures for the necessary disinfection of the handpieces and the switches and gauges in use in general dental practice.

In purely economic terms, one must consider not only the initial cost of the apparatus, but also subsequent maintenance and repair costs. Maintenance contracts are especially important for high-value microscopes to maintain their function and guarantee quick delivery of a replacement device if "something goes wrong."

18.18 Comparison of dental microscopes

Manufacturer	Zeiss	Leica	Kaps	Möller Wedel	Sigma Dental Systems
Product	**ProErgo**	**M525 F40**	**SOM 62 MOT**	**Universa 300**	**Global 6DX**
Eyepiece	10× or 12.5×	10× or 12.5×	6.3×, 10×, 12.5×, 16×, 20×	10× or 12.5×	10×
Working distance	200–415 mm	207–470 mm	100–400 mm	185–285 mm 235–425 mm	250 mm
Magnification	Continuously variable	Continuously variable	5 steps or 1:6 zoom continuously variable	2.5–24× 5 steps	2.1–19.2× 6 steps
Focusing	Manual/motorized	Manual/motorized	Manual	Manual	Manual
Braking	Magnetic	Magnetic	Magnetic	Mechanical	Mechanical
Illumination	180 W xenon internal with replacement xenon 180 W	300 W xenon internal 150 W halogen	150 W halogen internal 180 W xenon external	150 W halogen internal 300 W xenon external	100 W xenon, Nova Lux, metal fume short arc lamp 500–1 000 h, external
Swivel tube	180°	180°	210°	160°	220°
Angled optics	Yes	Yes	Yes	No	Yes
Handgrips and function	Brightness Magnification Documentation	Brightness Magnification Documentation	None	Focusing	None
Filter	Orange Green	Orange Green	Green	Orange Green	Orange
Ray distributor	50/50 70/30	50/50 70/30	50/50	50/50	50/50 95/5
Photography	External	External	External	External	External
Video	Integrated or external	Integrated or external	Integrated or external	External	Integrated or external
Programmable	By user	By user	No	No	No
Objective lens protection	Yes	Yes	–	–	–

Before making a decision about purchasing a microscope, its planned use within the dental practice should be well considered and tested. Important initial factors are variable working distance and continuously variable magnification changes. Magnetic brakes and switches near the handpiece are important in daily clinical use.

With special regard to endodontology, over and above the needs of general dental practice, the microscope should have a capacity of up to ×30 magnification. The removal of fragments or dealing with ledges within the root canal beyond the middle third requires a high degree of magnification for minimally invasive sonoabrasive techniques.

The illumination required for such procedures can only be achieved with a 180-W xenon light source. The light has daylight color and a higher light intensity. Using Xenon lamps integrated in dental/clinical microscopes is preferable to using ventilator systems because they are less noisy and better protected from dust.

19 Determination of Working Length

Precise determination of working length is of critical importance for a successful endodontic outcome. Without knowledge of the exact working length, no root canal should be instrumented and/or filled. Nevertheless, determination of working length can present considerable problems for the clinician. The problems may derive from the definition of working length itself, and may also relate to the broad variation in root canal anatomy. In this regard it is important to consider all of the methods for determining working length (e.g., radiographic, electronic, and tactile determination), which can be applied either singly or combined. Problems and special situations must be recognized and effectively dealt with to ensure that the working length determination is precise for each root canal of each tooth undergoing endodontic treatment.

The endodontic working length is defined as the distance between a fixed coronal reference point (e.g., a cusp tip) and an apical reference point (the apical constriction). The dentist can arbitrarily determine the coronal reference point, but it must be clearly defined and reproducible (by another clinician and by the same clinician at a subsequent sitting). Clinical experience has shown that the best coronal reference point is a cusp tip. The defined reference point for each individual root canal must be recorded in the patient's chart.

The working length is marked on an endodontic file/instrument using a silicone rubber stopper. The apical reference point must also be defined, as described in detail below. Although the exact position of the apical end reference point is still controversial, it appears to be advantageous in virtually all cases to end root canal instrumentation in the area of the apical constriction and not to exceed this point (Tronstad, 1991).

The instrumentation and obturation of root canals should end at the apical constriction (physiologic foramen) for the following reasons:

- no apical injury;
- no injury to the periodontal ligament;
- maintenance of accessory lateral canals;
- no extrusion of root canal filling material;
- no apical transport of infected pulpal tissues;
- adequate compaction of the root canal filling against the canal walls;
- no infected tissue remnants within the canal.

The determination of working length should also take into consideration the condition of the pulp in each individual case. In the case of a vital tooth, the clinician's primary concern is to keep the apical wound as small as possible, while with a necrotic pulp the main concern is removal of all bacteria. Both of these objectives can be met by terminating the apical extent of root canal instrumentation in the region of the apical constriction. Considering that the apical constriction in many cases is a line and not a point, one can argue whether root canal filling in cases of pulpal necrosis should extend closer to the anatomic apex while with vital teeth it should end at the apical constriction.

While the coronal reference point can be determined arbitrarily, the position of the apical constriction must be determined using a measurement device. Because of the enormous anatomic variations in the region of the root tip (Hess, 1917; Meyer, 1961), this determination presents a considerable challenge to the clinician and his or her method(s) of measurement. Various studies have demonstrated that the average distance between the apical constriction and the anatomic apex is 1 mm. However, this value varies with a range of 0–4 mm (Kuttler, 1955; Green, 1956; Dummer et al., 1984). For these reasons, the use of "average values" for the determination of the apical endpoint for instrumentation is clinically unacceptable.

Clinical Methods for Working Length Determination

The following methods can be used for determination of the position of the apical constriction:

- radiographic measurement;
- electronic method;
- tactile length determination.

Radiographic measurement

This technique has also been referred to as an "instrument contrast radiograph" and is the most widely used method for the determination of working length. If the film packet is positioned for the parallel radiographic technique, held in a film holder, the anatomic apex of the tooth can be determined and directly observed (in this case it is congruent with the radiographic apex). On average, the distance from the anatomic apex to the apical constriction is 1 mm. For this reason, the radiograpically determined working length should be 1 mm shorter than the distance between the coronal reference point and the anatomic apex. However, because of the range of anatomic variation described above, even this measurement determination may be somewhat less than precise.

Numerous research studies on extracted teeth have demonstrated that the apical constriction resides between 0 and 4 mm from the apex (Kuttler, 1955; Dummer et al., 1984). This could lead to over-instrumentation or under-instrumentation in cases in which the clinical apical endpoint is established (e.g., radiographically) 1 mm from the anatomic apex.

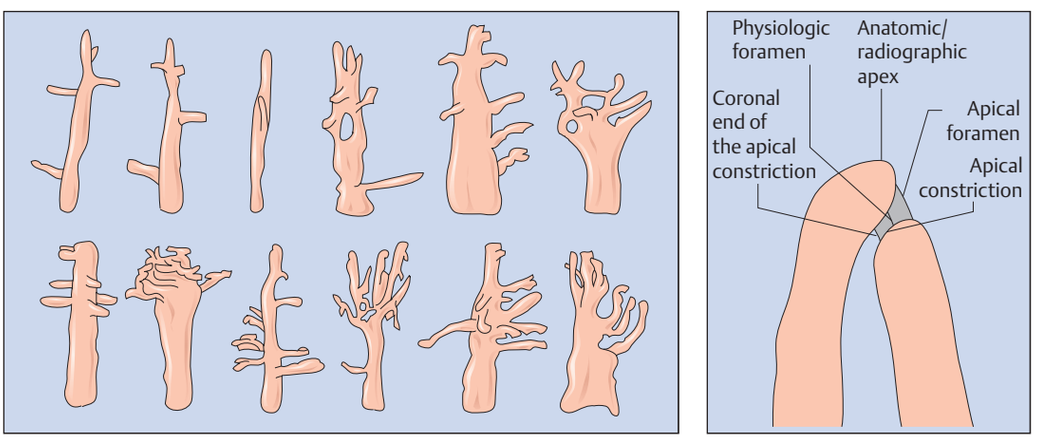
With these facts in mind, it becomes clear that radiographic determination of working length is not an exact science but rather a potentially arbitrary method. On the other hand, radiographic determination provides many additional details and information (canal curvatures, accessory canals, obliterated canals, obstructions), which the other two methods for working length determination cannot provide.

Even when using eccentric radiographic projections, there still may be uncertainty about the arrangement of the individual canals lingually or buccally in the case of root canals that overlap in a radiographic projection (mesial root canals of mandibular and maxillary molars and maxillary premolars). For this reason, during the preparation of radiographic images, only one root canal system should be instrumented at a time or different types of instrument types should be used in the various canals (K files, Hedström files). It is also prudent to always use the same instrument in the same canal (e.g., buccal). This will simplify examination and evaluation of the radiographs even at a later date.

19.1 Root canal anatomy

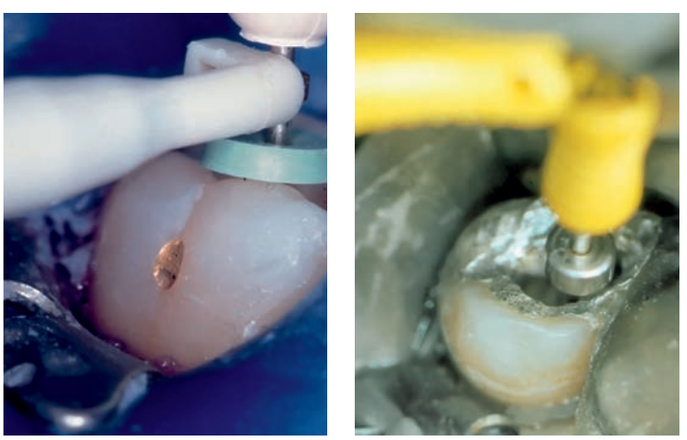
Structural anatomy of root canals: there are numerous patterns of ramification and the position of the apical constriction is variable.

Right: Schematic depiction of the root tip. A linearly shaped constriction will terminate apical to the physiologic foramen.



19.2 Stopper

Root canal instruments are used with metal or silicone stoppers to mark the working length. The stopper must clearly correspond to a cusp tip and rest firmly on it. For electronic determination of working length, the silicone stopper (left) is better than a metal stopper (right) because the metal stopper can cause a short circuit.

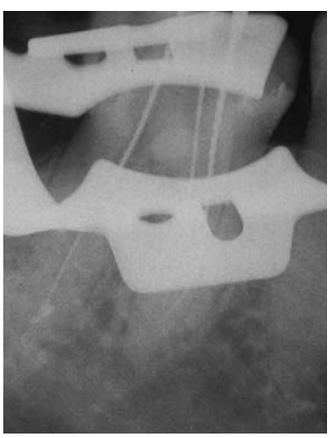


In addition to the well-established advantages of digital radiographic systems (e.g., reduction of radiation load, rapid availability of image, no need for developing chemicals, etc.), in endodontics, digital systems offer further specific advantages: The minimal size of the root canal instruments used for working length determination must be ISO size 15 to be certain that the tip of the instrument will be visible on the resultant image, and that the image can be enhanced using computer software at a later date. Nevertheless, the use of a radiographic system involving a digital sensor may present some clinical problems during the taking of length determination images. This depends on the thickness of the sensor and the necessity of using a connecting cable. Both of these can render the taking of radiographic images more difficult under a rubber dam. Digital systems using foil sensors do not have this disadvantage.

Radiographs taken using the bisecting angle technique and panoramic radiographs are *not indicated* for determination of working length in endodontics. The image of the tooth that results in these techniques is not true to scale. Therefore it is virtually impossible to determine the root length precisely when the distance between the instrument tip and the root apex is excessive. When there is a distance of more than 3 mm between the instrument tip and the tip of the root on the radiographic image, another image must be taken, because the calculated working length in such a case will be inaccurate.

To monitor changes in existing apical lesions, follow-up radiographs should be taken in the same position and in the same projection to allow comparison with the baseline radiograph. For this purpose, plastic bite plates can be prepared and attached to the film holder device using "building blocks" from toy stores.

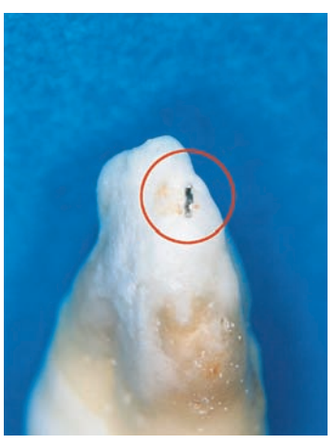
As an alternative to actual root canal instruments, silver points are also used for the radiographic measurement of working length, because of their higher radiopacity. Use of silver points permits a reduction in the minimal size of the instrument tip that is clearly visible on the radiograph from size 15 for steel instruments (size 20 for NiTi) to size 8. In addition, if using silver points, the tooth can be temporarily sealed and the rubber dam removed during the radiographic exposure, which significantly simplifies the procedure.



19.3 Radiograph for working length determination

Film holder in parallel technique for diagnosis, length determination, and follow-up. For length determination the rubber dam should be wholly or partially removed. Use silver points in temporarily restored teeth to avoid contamination.

Left: Superimposition of the clamp on the tooth influences image quality. Although in both mesial root canals of the maxillary molar different types of instrument were inserted, root canals cannot be definitively identified as mesiolingual or mesiobuccal.



19.4 Overlapping of structures

Left: This radiograph of an extracted maxillary molar shows the tip of the instrument to be within the root canal.

Right: The corresponding photograph clearly shows that the instrument has exited the root tip. However, owing to the overlap of the tip by the root structure, it appears to be within the canal in the radiograph.

Tactile Determination of Working Length

In the tactile method for determining canal length (working length), a root canal instrument of small ISO size is used to "feel" the apical constriction. While this method can be helpful for an experienced endodontist, it is not indicated as the single method for determining working length, and not just for forensic reasons. In the case of constrictions over a certain length of the root, only the coronal aspect can be determined with this method, and in roots with multiple constrictions only the first constriction will be determined.

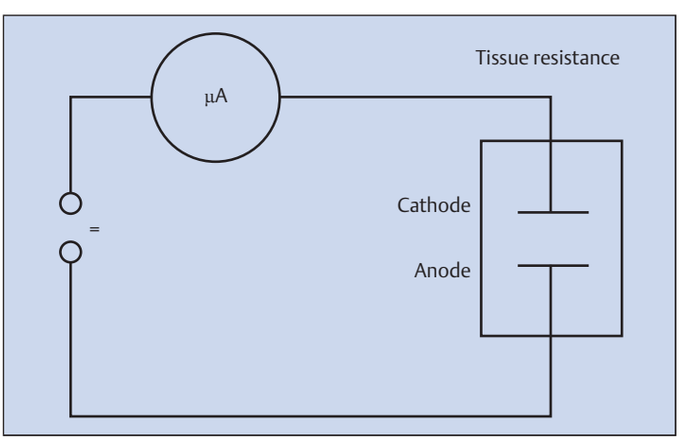
To check working length, it is helpful to place a paper point into the root canal before definitive obturation. The condition of the paper point (dry, moist, blood-stained) gives information about what the paper point made contact with in the apical region.

Electronic Method

The electronic method of determination of endodontic working length is based on the principle of measurement of electric resistance. This is currently the most accurate way to determine working length. As early as 1942, Suzuki demonstrated in a canine model that there is a constant electrical resistance of 6 kΩ between the oral mucosa and the periodontal fibers (Ushiyama, 1983).

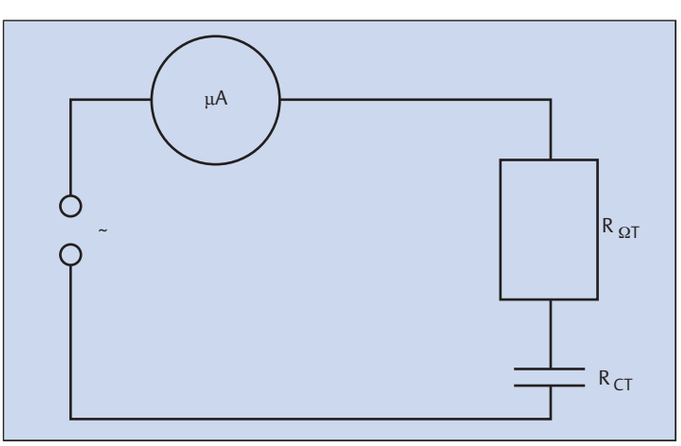
Sunada based the construction of his first electronic apex location system in 1962 on the fact that the periodontal ligament fibers are in direct contact with the apical constriction. He proposed that a resistance-measuring device with one electrode at the angle of the mouth and a second electrode attached to a root canal instrument should measure precisely 6 kΩ when the apical end of the root canal constriction was contacted by the root canal instrument. The *direct current* used with these first-generation apex locators, however, led to polarization of the instrument tip, and this made precise measurement impossible.

For this reason, subsequent generations of apex locators used *alternating current*. However, if there was fluid in the root canal, problems often occurred with the use of these devices. This is because the fluid caused a short circuit before the tip of the instrument reached the apex. In addition, measurements in a wet/moist root canal were rendered invalid owing to electrode impedance (alternating current resistance between the instrument tip and the surrounding fluid). This made it impossible to accurately measure the 6 kΩ tissue impedance. In addition, accurate measurements could not be made in the presence of apical periodontitis or incomplete root formation because the apical periodontal tissues in such cases were either destroyed or not yet formed (this was also a problem with first-generation apex locators).



19.5 First-generation apex locators: circuit diagram

Direct current flow diagram for a first-generation apex locator showing the electrical source, the measurement device, and tissue resistance. The use of direct current led to polarization of the instrument tip. The current flow became unstable and accurate measurement was not possible. A=Ampère



19.6 Second-generation apex locators: circuit diagram

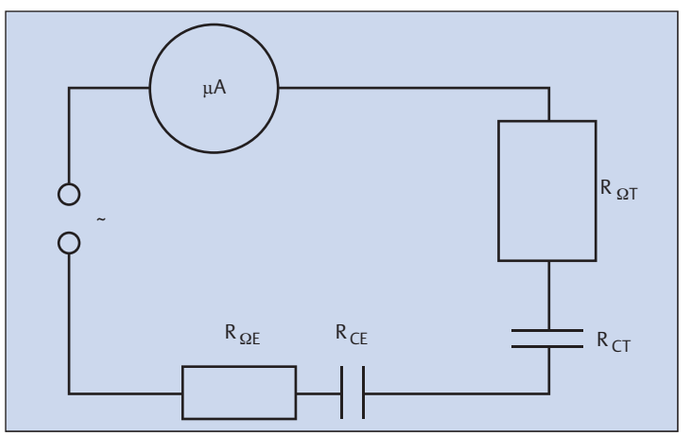
A second-generation apex locator for a dry root canal. Because of the use of alternating current, the tissue resistance has a capacitive (R_{CT}) and an ohmic ($R_{\Omega C}$) component. The original direct current in first-generation devices was replaced with alternating current. This prevented any polarization of the instrument tip. Problems of electrode impedance persisted in root canals that were not completely dry. (A=Ampère, T=tissue)

In the early 1990s, Kobayashi (1991) investigated these problems through the use of varying measurement frequencies. While using alternating current of varying frequencies, the ohmic resistance $R_{\Omega C}$ in the measurement cycle remains constant (if one alters the frequency of the alternating current); a change, however, can be noted in the capacitive resistance R_{CT}. Thus the tissue resistance can be measured despite the presence of fluid in the root canal. A microprocessor in the device provides relative values (difference or quotient). A measurement that is independent of the condition of the apical periodontal tissues can therefore be made by electrode impedance (alternating current resistance between the instrument tip and fluid in the canal). Apical and periodontal alterations/pathology and incomplete root growth are no longer of significance; even in these teeth, the working length can be accurately measured with an electronic apex locator.

In summary, modern apex locators provide information about the alternating current resistance between the instrument tip and the surrounding fluid. This electrode impedance is highest at the apical constriction and lowest at the apical foramen, because once the instrument tip traverses the narrowest region, it is no longer insulated by the dentin of the root canal wall and the current can flow abruptly in different directions toward the apex.

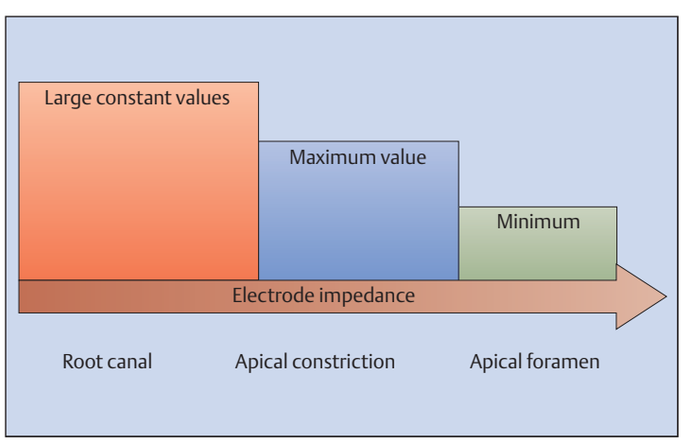
The position of the tip of the file between the apical constriction and the apical foramen will vary depending upon the conductivity of the dentin. Therefore the best estimate will be a description of the position of the file tip in the region between the "apical constriction and apical foramen" (Hör and Attin, 2001).

More accurate measurements can be achieved by means of calibrating the measurement device on extracted human teeth. Apex locators that have been calibrated on natural root canals (e.g., Raypex 4 and Raypex 5, VDW, Munich; Justy II, Hager and Werken, Duisburg, Germany) are capable of determining the location of the apical constriction precisely (95% positive for Raypex 4, 96.5% for Raypex 5).



19.7 Electrode impedance

Measurement circuit in a wet root canal. Because of the electrode impedance ($R_{\Omega E} + R_{CE}$), the tissue resistance ($R_{\Omega T} + R_{CT}$) reading is distorted and cannot be directly read. In the third generation of apex locators, this problem has been solved by use of various measurement frequencies. Using this technology, tissue resistance can be calculated (A = Ampère, E = electrode, R = resistance, T = tissue).



19.8 Alteration of electrode impedance

Alteration of the electrode impedance within the root canal. The electrode impedance is high within the root canal and constant, and achieves its maximum value at the apical constriction.
Beyond the apical constriction, the current flow can change abruptly in any direction. The active surface of the instrument becomes larger, and the electrode impedance reaches a minimum.

Clinical Use of Apex Locators

The devices described in this chapter require fluid within the root canal for measuring the working length. Therefore the canal should be irrigated before making the measurement and the access cavity dried with a cotton pellet. It is important to avoid any short circuit of the measurement circuit over the gingiva (metal restorations, crowns, perforations etc.). The measurement itself is carried out following the placement of a lip clip at the corner of the mouth and insertion of the apex locator into the root canal.

During the measurement phase so-called "false-positive" readings (apex locator tip not at the apex, while the device indicates the apex) and "false-negative" readings (instrument tip at the apex, device indicates that the instrument is not at the apex) may occur. The cause of a false-positive measurement is a short circuit. This can be caused by the presence of metal restorations, gingival overgrowth into the cavity, parapulpal pins, root fractures, lateral canals or false canals (perforation).

In the case of false-negative measurements, the cause is hindrance of the current flow. This can be due to presence of calcified root canals, remnants of old root canal fillings, canal blockage with secondary/tertiary dentin or insufficient irrigation during the procedure, or it can occur during retreatment.

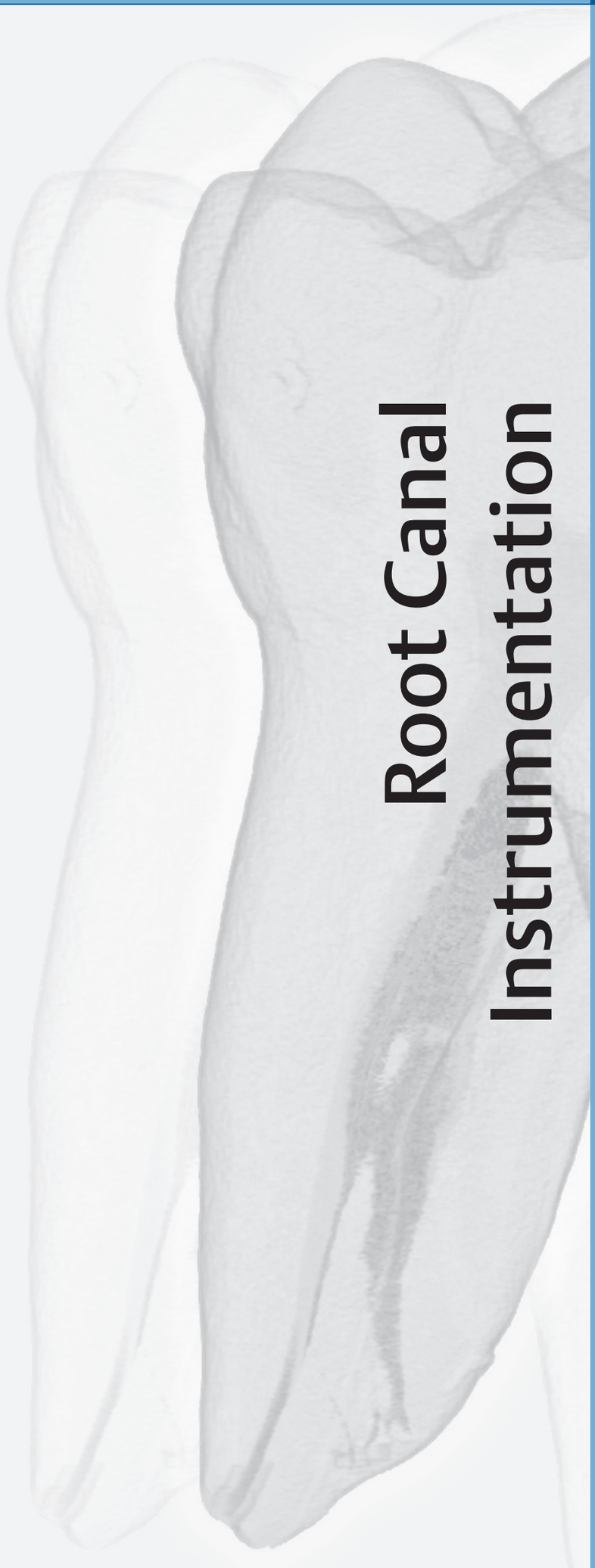
Tip: During the differential diagnosis stage, apex locators can be used to definitively confirm the presence of tooth fracture, perforations, or obliteration of root canals. They can also be used to test for apical patency.

Transferring of the Measured Values

The values obtained with an apex locator should be transferred to the root canal instrumentation files with great care because otherwise the precision of the entire measurement process will be lost. The importance of using silicone stoppers and the reproducibility of the coronal reference points has already been discussed.

It is also important to keep in mind that on teeth with build-up restorations there can be changes in the occlusal dimensions between two endodontic sessions. In such cases another electronic measurement should be carried out before canal obturation. Such measurements can help to avoid clinical errors, which are especially prone to occur in curved canals and are caused by some "straightening" of the root canal during instrumentation and a resultant shortening of the working length. In addition, extreme care should be taken when transferring the working length to the gutta-percha master point.

To avoid errors caused by a parallax view, all gutta-percha points should be cut to the working length with a scalpel. Nicking or marking the gutta-percha points using the beaks of the forceps can lead to inaccuracies and cast doubt on the entire determination of working length.



Root Canal Instrumentation

D

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20 Engine-driven Instrumentation Systems: History and Early Developments

Root canal instrumentation using purely hand instruments often represents a quite laborious and "boring" task, fraught with unavoidable problems.

As early as 1899, William H. Rollins developed the first handpiece for engine-driven instrumentation of root canals. The first commercially available handpieces allowed only limited motion in terms of speed and direction. In subsequent years, several improved systems were introduced to the marketplace. As well as combining rotary and up-and-down motion of the file, a special feature of these motors was their ability to respond to an increase in resistance caused by the instrument becoming wedged within the root canal. A clutch mechanism would change the motion of the instrument as soon as friction within the root canal increased, intended to reduce the danger of instrument fracture. However, owing to the use of stainless-steel instruments with these handpieces, the consequences very often included ledge formation, perforation, or even instrument fracture.

With regard to engine-driven root canal instrumentation, the "classic" systems have virtually no role today. This is because of the numerous mechanical nickel-titanium (NiTi) instruments that are now available and demonstrate high cleaning efficiency and intracanal effectiveness.

The Racer system, introduced in the 1950s, was the first endodontic handpiece for engine-driven root canal instrumentation that gained a significant market advantage. It allowed a purely vertical motion. However, there were frequent reports of instruments becoming wedged in the root canal, and even instrument fracture.

The development of the rotatory motor led to improved canal instrumentation. The Giromatic system, introduced in 1964, was widely accepted and used. Its reciprocal 90° rotatory motion made possible rapid and simple root canal instrumentation. This instrument motion within the canal was also adopted by other systems. The Endolift M4 motion had a smaller rotational component of 30°. The vertical motion of the handpiece could be controlled by clinicians themselves.

With the introduction of the Endolift (Kerr), a system became available on the commercial market that combined vertical with a reciprocal 90° rotary motion. Later Kerr sought to improve the rigid vertical motion by incorporating a more flexible-type motion. The Excalibur system combined for the first time aleatoric oscillations with a variable-amplitude vertical motion.

The Endoplaner system provided a combination of filing (vertical) and rotary motion. The Canal-Finder device had the ability to deliver vertical motion, as well as free rotation with increasing intracanal friction. The Canal-Leader system had similar motion characteristics, but with more limited vertical as well as partial rotatory movement.

The Intra-Endo 3-LDSY offered a combination of vertical and free rotary motion as soon as the instrument was too heavily loaded in the axial direction. The IMD 9X exhibited a 360° rotary movement but the speed of rotation was reduced with increasing friction within the canal. It was only with the ENDOflash that a torque-dependent rotational speed was controlled from within the handpiece.

Engine-driven Systems for Root Canal Instrumentation Using Stainless-steel Instruments

In the literature, engine-driven systems for root canal instrumentation are basically considered inadequate or insufficient with regard to the safety of the procedure and the final shape/form of the prepared root canal. Because even the cleansing effect is not ideal, the conventional motor systems incorporating a rigid range of motion are no longer recommended.

More modern systems with a flexible range of motion and partially integrated irrigation systems provide markedly improved root canal cleaning and represent some progress in this field. Nevertheless, today's modern NiTi instruments are a better preparation alternative, so that no conventional system merits recommendation.

Several recent publications do support the use of more flexible systems such as Canal-Finder and Canal-Leader 2000 for use in narrow and/or curved root canals. In addition, foreign bodies such as fractured instruments or previously placed root canal fillings can be reliably removed during retreatment using both systems. Today, the best alternative for retreatment includes engine-driven NiTi instruments.

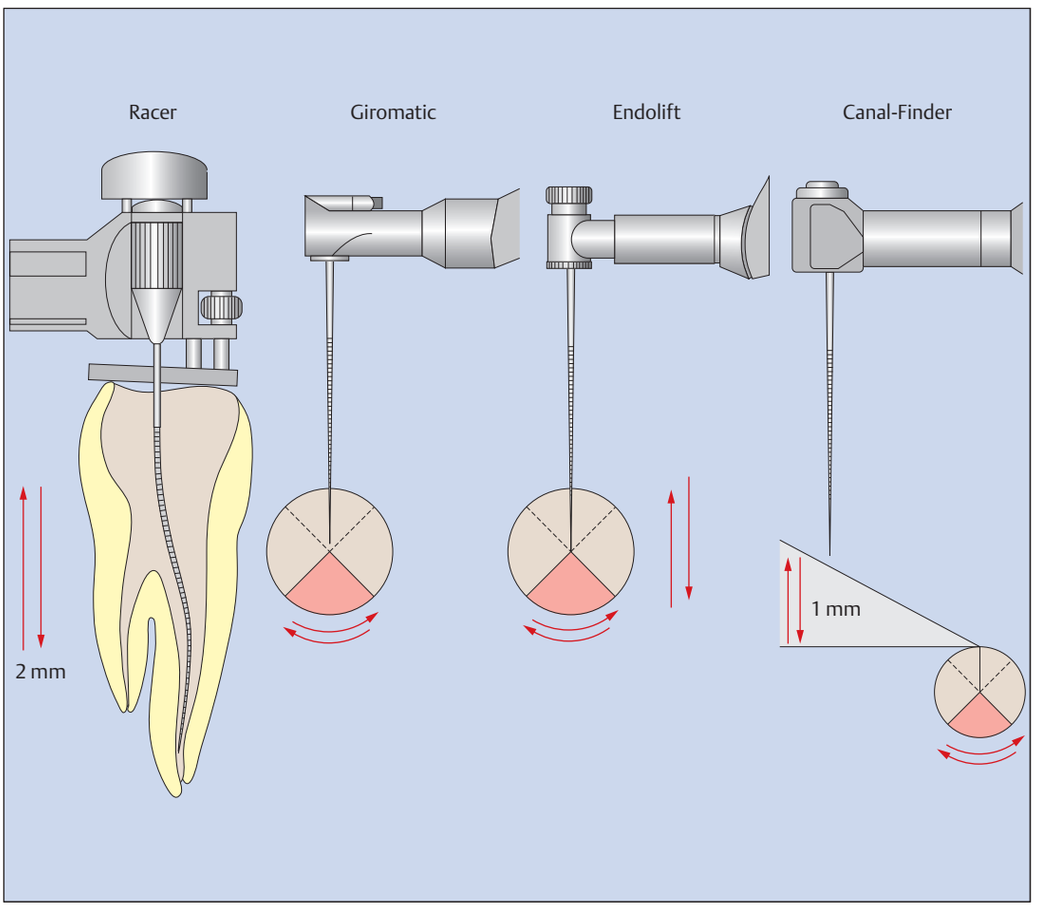
20.1 Mechanism of action of various engine-driven endodontic handpieces

Left: The Racer handpiece: rigid vertical movement.

Middle, left: Giromatic handpiece: rigid, reciprocal movement.

Middle, right: Endolift: rigid vertical movement plus simultaneous reciprocal rotation.

Right: Canal-Finder: flexible vertical movement plus friction-dependent free reciprocal rotary motion.



20.2 Overview of conventional engine-driven endodontic instrumentation systems

Left: Systems with rigid motion.

Right: Systems with flexible motion.

Racer (Cardex)	Vertical motion	Excalibur (W&H)	Lateral oscillation from about 2000 Hz; vertical motion amplitude: 1.4–2 mm
Giromatic (MICRO-MEGA)	Reciprocal rotation (90°)	Endoplaner (Microna)	Filing motion with tension and free rotation
Endo-Gripper (Moyco)	Reciprocal rotation (90°)	Canal-Finder (SET)	Vertical motion of 0.3–1 mm and free rotation with friction
Endolift (Kerr)	Vertical motion and reciprocal rotation (90°)	Canal-Leader 2000 (SET)	Vertical motion of 0.4–0.8 mm and rotation from 20° to 30°
Endolift M4 (Sybron)	Reciprocal rotation	Intra-Endo 3-LDSY (KaVo)	Vertical motion and free rotation with axial loading
ENDO Cursor (W&H)	Rotation (360°)	IMD 9GX (HiTech)	360° rotation with variable, torque-dependent rotation
Intra-Endo 3 LD (KaVo)	Reciprocal rotation (90°)	ENDOflash (KaVo)	Torque-limited rotation
Dynatrak (Dentsply)	Reciprocal rotation (90°)		

Even today, the development of engine-driven handpieces for root canal instrumentation continues. The KaVo-ENDOflash system uses steel instruments, and entered the commercial market several years ago.

The Endo-Eze (AET) handpiece (Ultradent) with its clutch mechanism is designed for the instrumentation of oval root canals. The removal of dentin from the canal wall is quite significant, but especially in curved canals straightening occurred (Paqué et al., 2006).

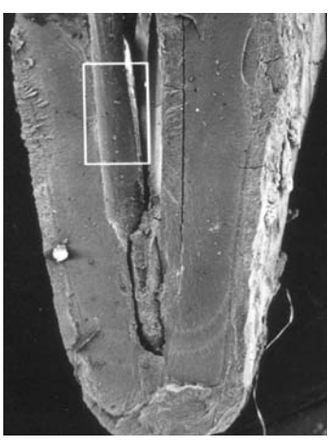
A recently introduced system from Essential Dental Systems (EDS) provides for the use of steel and/or NiTi instruments in a special handpiece. The mechanism of action corresponds to the balanced-force technique as described by Roane et al. (1985).

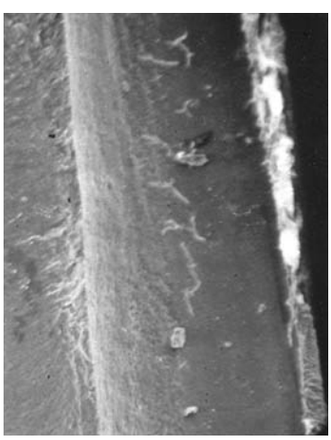
Sonic or ultrasonic instruments are no longer recommended today for root canal instrumentation because of the danger of instrument fracture and root canal alterations. Rather, these technologies are ideally suited for removal of dentin overhangs, cemented posts, cement or paste fillings during retreatment, and especially for cleaning of the root canal (van der Sluis et al., 2005).

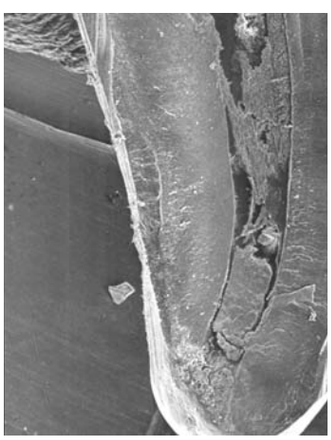
20.3 Engine-driven handpieces

Left: Endolift (Kerr) with a K file in situ. Note the relatively large size of the handpiece, which can limit access in the molar segments.

Right: Canal-Finder handpiece (SET) with a K file from the Canal-Finder sequence.





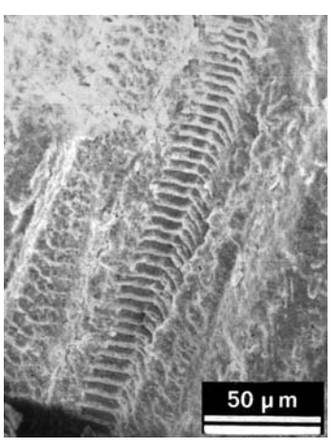


20.4 Electron microscopic examination

Left: Apical blockage leading to shortening of the working length.

Middle: This section reveals irregularities in the root canal wall.

Right: Massive blockage with shortening of the working length following engine-driven instrumentation of a curved canal using stainless-steel files.



20.5 Ultrasonic-driven instrumentation of the root canal

Left: Sonically activated K file with active rinsing function.

Right: The electron photomicroscopic view of the root canal wall reveals obvious roughening of the dentin surface caused by the cutting edges of the K file (courtesy of A. Petschelt).

21 Power-driven Instrumentation Systems: Recent Advancements

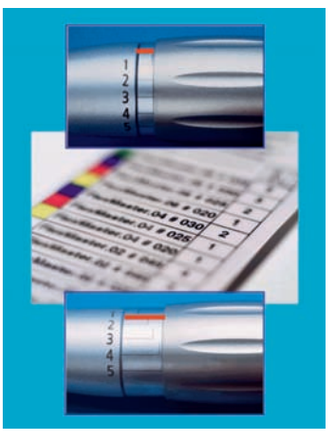
Since the end of the nineteenth century, numerous attempts have been made to develop power-driven instrumentation systems that would provide an appropriate and effective alternative to conventional manual root canal instrumentation.

With the introduction of NiTi instruments for root canal instrumentation in 1988 by Walia et al., a new era began. The fully rotating (360°), power-driven instrumentation files made of NiTi alloys led to significant improvements for mechanical systems (Schäfer, 2001). The most significant advantage of this technique is the excellent instrumentation of severely curved canals, with significant savings in clinical root canal preparation time (Bryant, 1999).

A problem, however, in comparison to the purely manual use of stainless-steel instruments is the high risk of fracture, which necessitates torque-limited power (Hülsmann, 2002).

21.1 Handpiece

Torque-limited handpiece (SIRONiTi). The clutch mechanism (right) allows selection of the desired torque interval.



21.2 The motor

Torque-regulating motor (EndoStepper) with the appropriate handpiece (right). The torque is selected via a preprogrammed system.

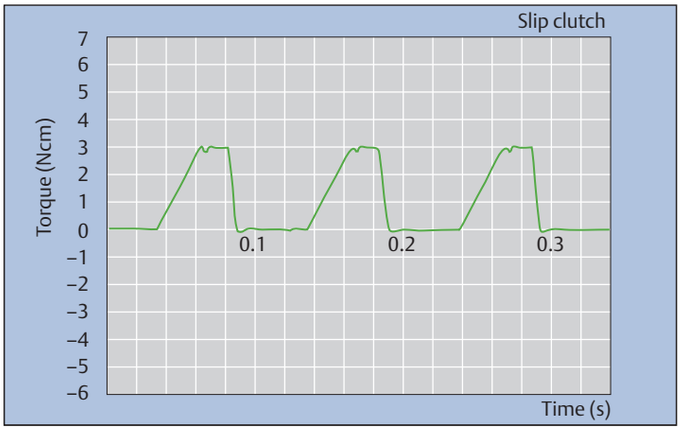
To avoid the instrument becoming stuck and fracturing within the root canal, the instrumentation must be performed at a low constant speed (usually approximately 300 rpm) (Hülsmann, 2002).

In addition to the experience of and careful instrumentation by the clinician, as well as the speed, torque also influences the risk of instrument fracture (Yared, 2001). For this reason, numerous technical solutions incorporating limitations on torque have been tried to reduce the fracture rate. Today's instruments comprise torque-limited handpieces powered by torque-regulated electric motors.

The torque limitation controls the rotation of the instrument within the root canal, as this is interrupted the instant that frictional resistance to the file exceeds the fracture limit of the instrument (Merte, 2003).

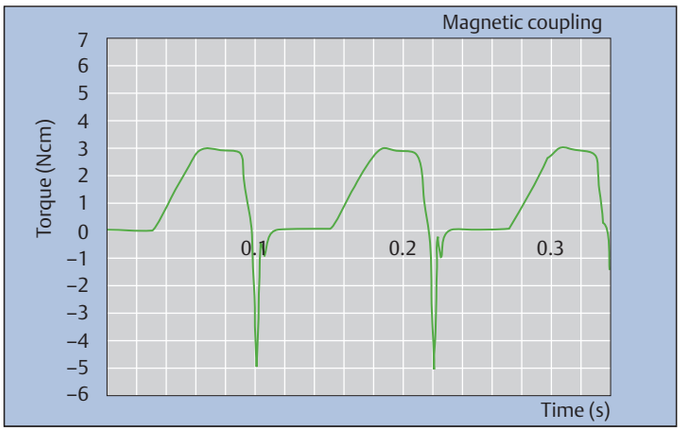
Torque-limited reducing handpieces work by means of multi-level control of maximum torque. This group of handpieces includes the Anthogyr NiTi control (Dentsply), which incorporates a friction clutch in the handpiece and four-step regulation. On the other hand, the SIRONiTi handpiece (Sirona) has a magnetic clutch with five levels of regulation. Different torque step levels inevitably lead to the problem of how to classify instrument groups.

To overcome the above problem, root canal files of varying mechanical capacity are grouped depending on the level of clinical safety. The weakest instrument within a group provides the maximum torque. The significance of this fact is that not all files within a group will be taxed to the maximum, and their maximum dentin cutting efficiency could be reduced by the somewhat lower torque.



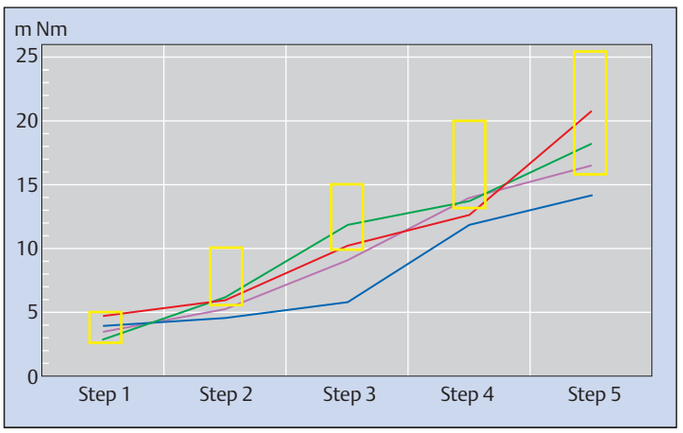
21.3 Sliding clutch

Torque-limited handpiece with a sliding clutch (Anthogyr NiTi Control, left), and a force-time diagram. If a predetermined level of torque is exceeded, the device comes to a standstill.



21.4 Magnetic clutch

Torque-controlled handpiece with a magnetic clutch (SIRONiTi, left) and a force-time diagram. If the predetermined torque level is exceeded, the related force is decreased until the device comes to a standstill. The resulting effect is a reverse movement of the instrument (reverse rotation) to "release" the instrument within the canal.



21.5 Evaluation of torque control

Evaluation of torque limitation using an electronic sensor. Measurement values for the five adjustable torque intervals (in m Nm) of the SIRONiTi device were evaluated in four randomly selected handpieces. The values were slightly below those provided by the manufacturer.

Torque-control micromotors provide control of torque within the motor itself. Some of the commercially available devices are computer-controlled step-motors, which in contrast to conventional micromotors do not work with a continuous 360° rotation, but rather move through 1600 identical steps of 0.225° (EndoStepper, Phytron).

Torque-control motors are classified according to their torque capacity and speed (rpm), and/or file-specific programming capabilities. Torque-control motors with step-specific torque programming include ATR Technika (Dentsply), K3etcm (Kerr), TCM Endo (Nouvag), TriAuto ZX (Morita), and Quantec ETM (SybronEndo). In contrast, the EndoStepper (Phytron) and Endo IT Control (VDW) are torque-control motors in which torque is programmed according to the file used (Merte, 2003). In addition, these motors provide various mechanisms for disengagement and release of blocked instruments (auto-reverse function/twisting).

21.6 Drive motor systems

Examples of various motor systems.

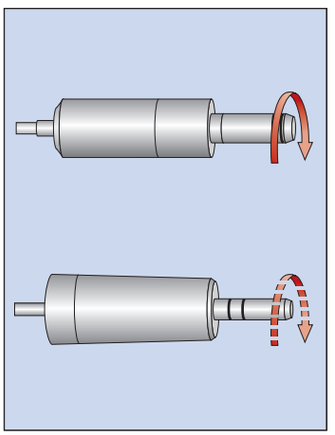
Left: TCM Nouvag:
- 1000–30 000 rpm
- Controllable speed (10–55 Ncm)
- WS 1:1–20:1

Right: ATR Tecnika
- Program
- Auto-reverse
- WS 16:1

21.7 Micromotor versus step-motor

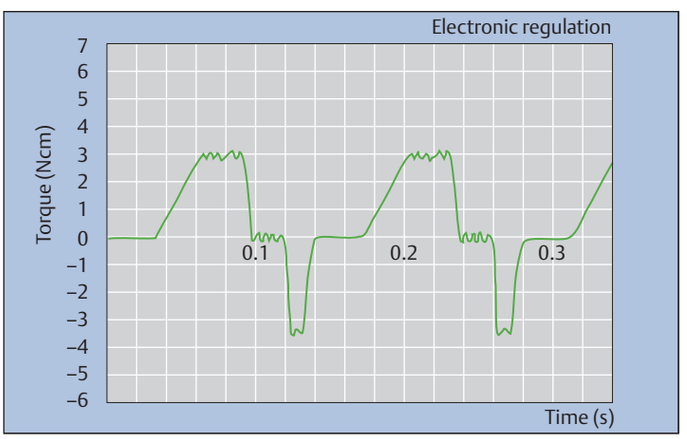
Left: EndoStepper:
- Step-motor
- Program
- "Endo-twisting"
- WS 1:1

Right: In contrast to the micromotor, the step-motor achieves 360° rotation through numerous individual steps (e.g., 1600).



21.8 Torque control

Force-time diagram from an electronic, torque-limited motor. When a preprogramed torque limit is achieved, the endodontic instrument stops its motion and the direction of the motor is altered in order to release the endodontic instrument from its blocked position in the canal.



Power-driven root canal instrumentation using NiTi files is generally done according to the principle of the crown-down technique. It is important not to impinge on the apical constriction while performing this procedure.

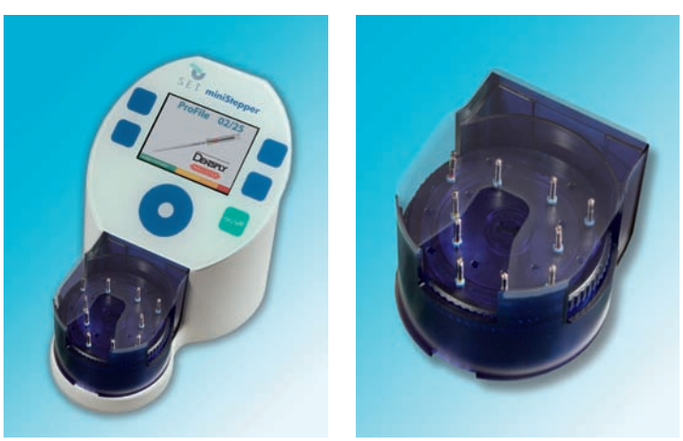
In addition to traditional radiographic measurement techniques, today's endodontist has an effective alternative for checking the working length. For truly ergonomic work and continuous process control it is therefore prudent to integrate electronic apex localization throughout the power-driven canal instrumentation process. To this end, modified endodontic handpieces have been developed (e.g. SIRONiTi APEX) which, through specially constructed mechanisms, do not impact the electronic working length determination during instrumentation. In addition, power-driven devices must be usable with new file systems, for example through modification of torque (the handpiece) or electronic stepped controls (the motor).

21.9 Torque-limited handpiece

Torque-limited handpiece with attachment for an electronic apex locator (SIRONiTi APEX). Various conventional and commercially available apex locators can be attached.

21.10 Torque-limited motor system

Torque-limited motor system with integrated electronic apex locator. During instrumentation of the root canal, the estimated length is electronically and continuously displayed.



21.11 Automatic identification of the file parameters

Clinical working system providing automatic identification of the specific file parameters. After removal from the "smart box" (right) of the SET miniStepper system (left), the motor parameters are automatically adjusted for individual files.

22 Fracture of Endodontic Instruments: Torque and Fatigue

One of the complications of endodontic treatment most dreaded by clinicians is the fracture of an instrument within the root canal. Even though instrument fractures per se are not regarded as a professional error, the patient must be informed. Inadequate disinfection of the root canal system before instrument fracture can affect the prognosis of the treatment (Spili et al., 2005).

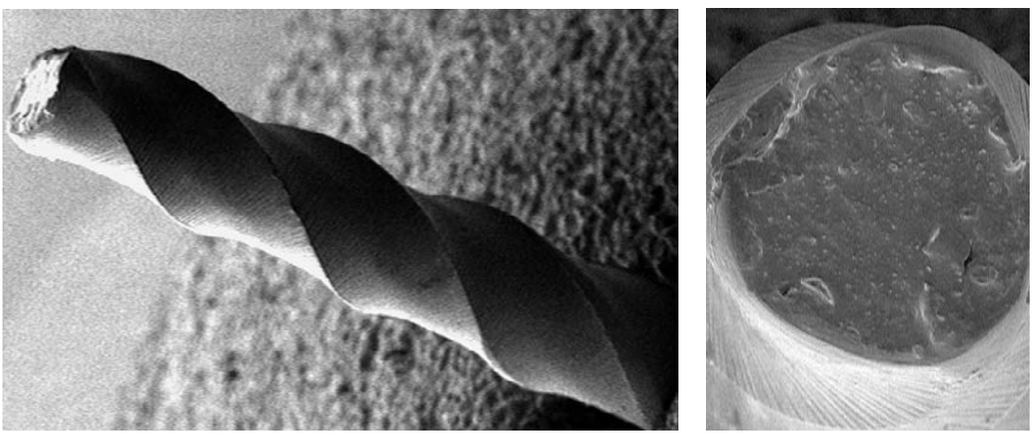
Endodontic hand instruments fabricated from stainless steel are less susceptible to fracture, and when this occurs it is usually due to improper technical use. The rotary movement of Hedström (H) files and the use of excessive force with small diameter files are usually the primary culprits.

Stainless-steel instruments undergo a clearly discernible plastic deformation before fracture. With rotary NiTi instruments, plastic deformation occurs less often; in certain situations these instruments can fracture without any warning. Overall, fracture of rotary NiTi instruments is somewhat more common than of K files made of stainless steel (5.1% vs. 3.3%, respectively; Spili et al., 2005). Thus for effective clinical use of rotary instruments, a thorough understanding of fracture mechanisms is very important.

22.1 Cyclic fatigue

Scanning electron photomicrograph showing a fragment of a Flex-Master instrument (VDW) of size 25 and taper 0.6. The cutting edges do not exhibit any plastic deformation.

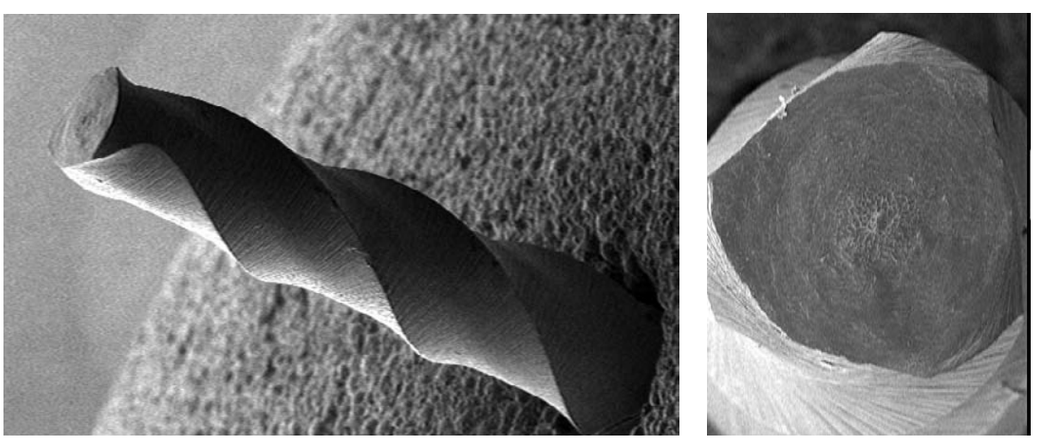
Right: This cross-sectional view reveals a somewhat "lumpy" but nevertheless homogeneous surface.



22.2 Torsion loading

Scanning electron photomicrograph of a fragment of a Flex-Master instrument of size 25 and taper 0.6. Plastic deformation of the cutting edges is clearly visible toward the break surface.

Right: This cross section of the instrument shows a netlike pattern in the middle of the instrument, which is typical after torque loading.



Sattapan et al. (2000) described two different mechanisms for the fracture of NiTi instruments: cyclic fatigue and torsional overloading. Cyclic fatigue of instruments is the result of local work hardening (which makes the file brittle) and eventually leads to fracture. As there is no plastic deformation before this occurs, there are no warning signs of cyclic fatigue.

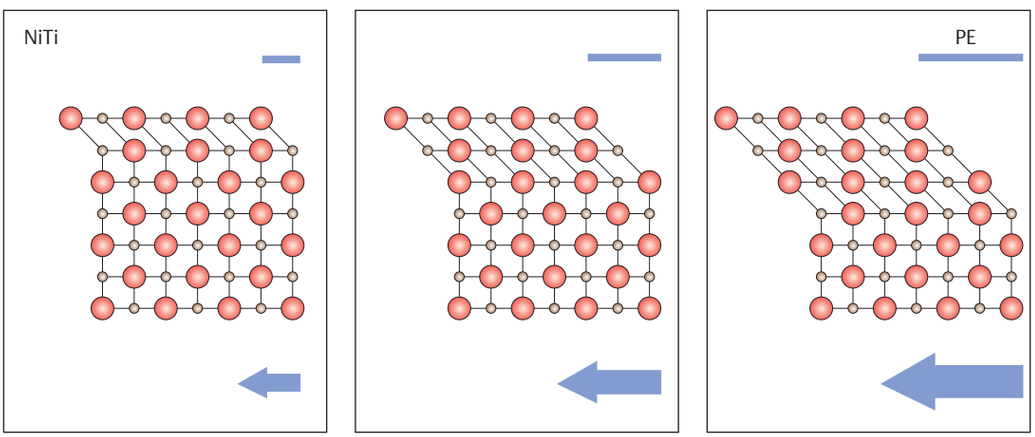
In contrast, with torsional loading one may note deformation of stainless-steel instruments and occasionally also of instruments made of NiTi alloy. For this reason, all rotary instruments should be visually inspected before reuse after sterilization.

Recent analyses and evaluations demonstrate that both factors are present together clinically and influence each other reciprocally: Fatigue reduces torsional resistance, and vice versa (Fife et al., 2003, Ullmann and Peters, 2005). Additional factors include possible corrosion and the quality of the instrument material, as score marks left on the surface of the instrument during the manufacturing process can be the starting point for cracks and subsequent fracture.

Crystal Structure of Nickel-Titanium and Steel

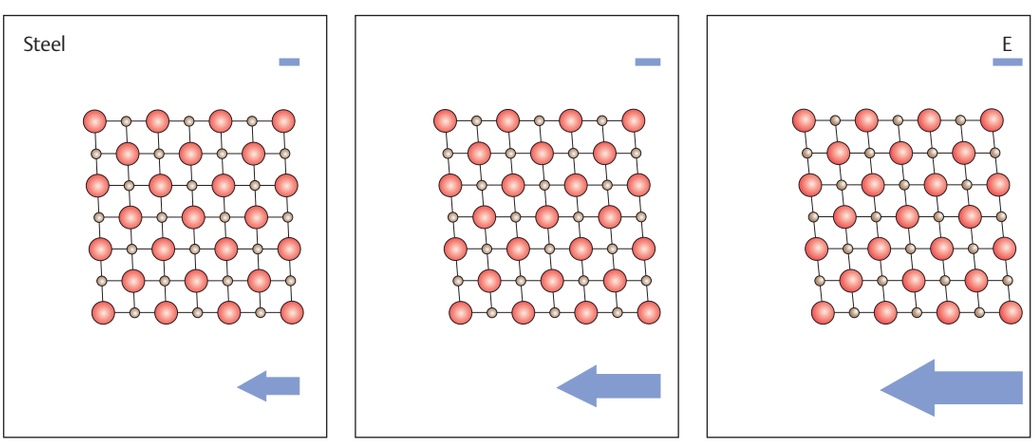
In contrast to stainless steel, NiTi alloys exist as two different crystal structures (Thompson, 2000): austenite and martensite. At room temperature NiTi assumes its austenitic configuration; with the application of force/tension or with temperature change, the alloy can change its conformation into the stable martensite form. This process permits a reversible deformation of about 7%. To prevent instrument fracture, the degree of deformation must remain below this percentage, because further deformation will weaken the instrument irreversibly, but without any clinically obvious signs.

Instruments within a root canal are loaded rotationally, not linearly. Of importance in this regard is the process of "relaxation" in addition to cyclic fatigue. If the tip of the instrument becomes lodged within the canal, the coronal end of the instrument can often be rotated another two full rotations with reduced torque. Immediately thereafter a torsional overload will occur, leading inevitably to instrument fracture. Clinically, the torsional overload is simpler to avoid than fatigue breakage but requires special attention to, and analysis of, the root canal anatomy.



22.3 Pseudoelasticity

The special crystal structure that permits phase transition from the austenite to martensite allows the NiTi alloy to undergo a linear deformation of about 7% with increasing tension (size of the arrow), without the occurrence of any permanent deformation.
This characteristic is described as pseudoelasticity (PE).



22.4 Elasticity

In contrast to NiTi, stainless steel has a significantly lower potential for elastic deformation. This means that such instruments experience cyclic fatigue earlier because each individual microcycle reaches the range of plastic permanent deformation more quickly. The elastic deformation (E) is significantly smaller than the pseudoelasticity (PE) of NiTi.

To protect rotating NiTi files from fracture, use of torque-controlled motors and special instrument handling are recommended. The establishment of a patent canal ("glide path") before the use of rotary files with thin tips permits the subsequent use of tapered instruments with reduced danger of fracture in curved canals. This initial instrumentation should be carried out with non–pre-bent hand instruments of ISO sizes 10, 15, and 20.

If the taper of the canal is smaller than that of the instrument (file), an increased crown-down instrumentation is recommended. Appropriately shaped NiTi instruments can also be used in the stepback technique. Prerequisites for this procedure include smaller instrument taper and a root canal course without abrupt curves or ledges. Continuous progression (e.g., GT files) or an intermittent hand movement is recommended. These techniques spread material fatigue over a larger area and protect the instrument tip from taper lock.

Stiffer instruments with sharp cutting edges can be used to advantage with lateral pressure brushing. This procedure will avoid "threading" the file into the canal, and permits shaping of the canal away from thin areas of the root canal walls (e.g., the furcation area of mandibular molars), especially during instrumentation of the mesial root canals.

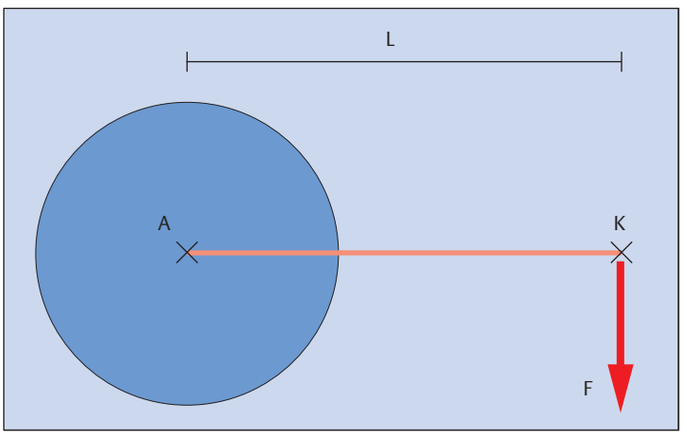
Torque

Force applied to any material will set the material in motion; but if the material is held constant at a fixed point, application of force results in a twisting or rotational movement. This movement is the product of the force and the direction of application of the force. A clinician can control friction within the root canal by the application of appropriate force.

The friction itself is influenced by the shape/form of the cutting edges of the endodontic instruments and the structure of the dentin. That means that the torque necessary for rotation within the canal must increase in accordance with the diameter of the instrument used, and the extent of the contact surface between the dentin and the instrument. Experiments (Blum et al., 1999) and clinical experience have demonstrated that "crown-down" (coronoapical) instrumentation reduces the extent of the contact surface, thus leading to less torque. The breakage torque of the instrument tip is measured according to ISO norms 3 mm from the tip and can be correlated with the working torque of each individual instrument. Motors with torque limitation can be programmed from such data. The use of such motors leads to less loading of the nickel-titanium files, and therefore improved longevity (Gambarini, 2000).

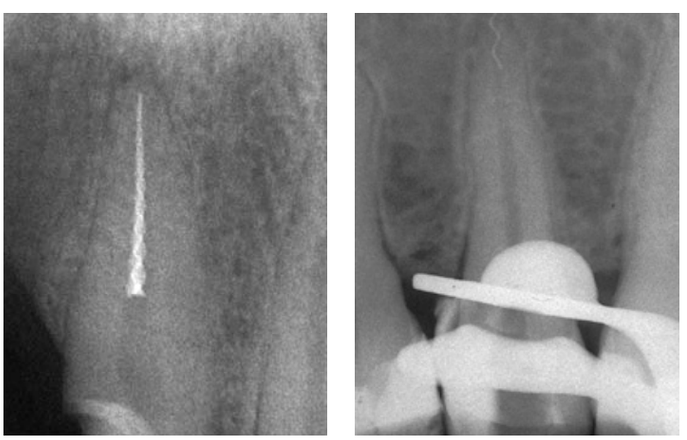
22.5 Torque

The rotation of an object around its axis A creates a force (F) that exerts a lever effect at point K. This force overcomes friction and product mass. By multiplying the force, measured in newtons (N) by the length (L) of the lever arm, measured in centimeters (cm), one can calculate the torque in "N cm" (SI unit).



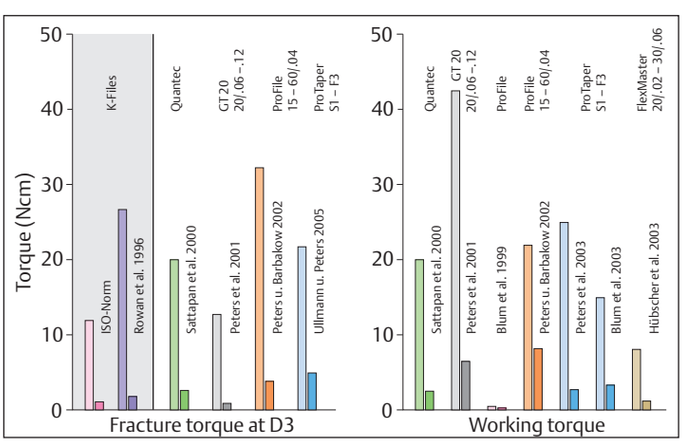
22.6 Clinical example

Instrument fracture is less common in straight root canals. If a long fragment of an instrument is stuck in the canal and a torsion fracture is suspected (left), surgery may be required to remove the fractured instrument fragment. The same is true for a left-rotating lentulo spiral fracture in the apical third of the root (right).



22.7 Torsion resistance

The schematic representation displays the fracture torque 3 mm from the instrument tip (left) in comparison to working torque (right). The values for the smallest and largest instruments within an endodontic set are displayed with the references. It is noteworthy that in many cases the working torque exceeds the fracture limit at D3.

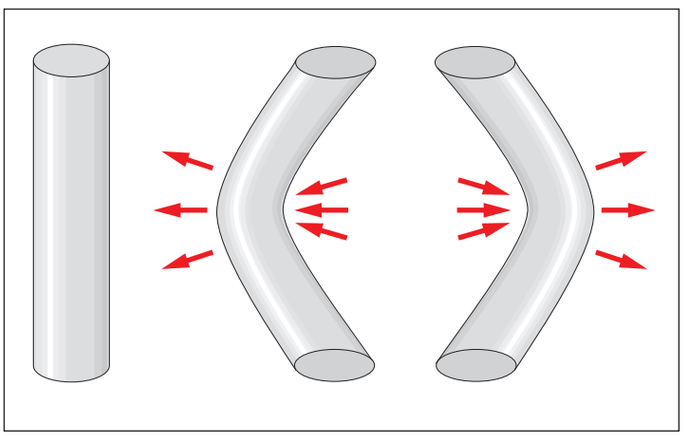


Fatigue

Rotation around an axis or undulation, combined with lateral application of force, leads to bending forces and premature material fatigue. One can differentiate between high-cycle fatigue (number of cycles to fatigue: >10 000) and low-cycle fatigue (number of cycles to fatigue: <10 000). This phenomenon is described as "cyclic fatigue."

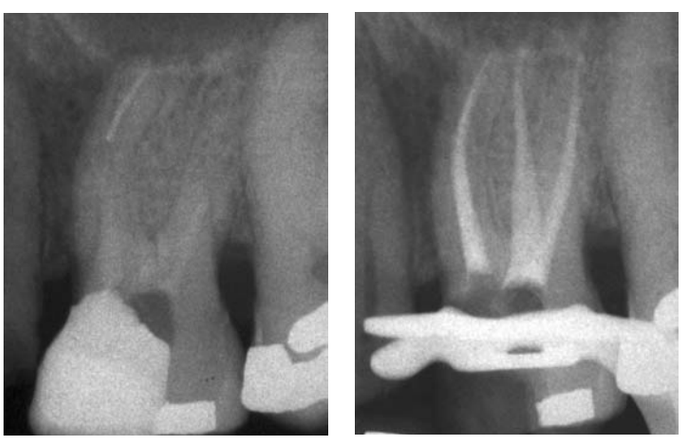
When used in curved root canals, rotary instruments will break after time; experiments show that breakage will occur after 300–600 rotations or a usage time of 1–2 minutes in a severe curve. In addition, manufacturing defects or microcracks play a role in the occurrence of fatigue-induced fracture.

In the clinical situation it is important to minimize the time the instrument is actually in the canal. After about 10–15 seconds of use, the instrument should be removed from the canal. Thus the usage time or lifespan is limited. There has been speculation that microscopically small plastic deformations remain, thus leading to reduced fatigue resistance (Gambarini, 2000). In addition, a relationship exists between cyclic fatigue and lower torsion resistance (Ullmann and Peters, 2005). This applies more to instruments with larger diameters and/or higher taper than to instruments with smaller dimensions.



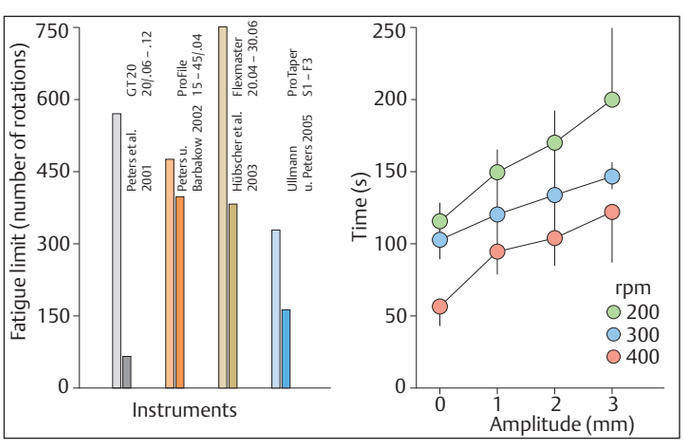
22.8 Cyclic fatigue

If a metal cylinder is bent, opposite sides will experience areas of tension and pressure, as represented here by the red arrows on the inside and outside of the bend. In rotation of the cylinder, or of the root canal instrument, this phenomenon is reproduced once per rotation. With time and material fatigue, fracture can occur.



22.9 Clinical example

Cyclic fatigue as the cause of instrument fractures is usually seen in curved root canals. Both in maxillary and mandibular molars, the middle third of the root canal is often curved, and this can pose problems for instruments of larger taper. In this example, it was not possible to remove the instrument fragment.



22.10 In vitro data

The left graph illustrates instrument lifespan as measured on a steel model with a 5-mm radius and 90% curvature. The right graph displays the effect of oscillating movement (recalculated from Li et al., 2002). For the ProFile 25/.04, there is a linear increase in the lifespan. This relationship could not be demonstrated for instruments of larger diameter (Peters and Barbakow, 2002).

23
File Systems

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Alpha System

The Alpha system, developed in 2005, consists of NiTi instruments with tapers of 2%, 4%, 6%, and 10%. The ISO sizes range from 20 to 50. The Alpha files are commercially available in two different cross-sectional conformations.

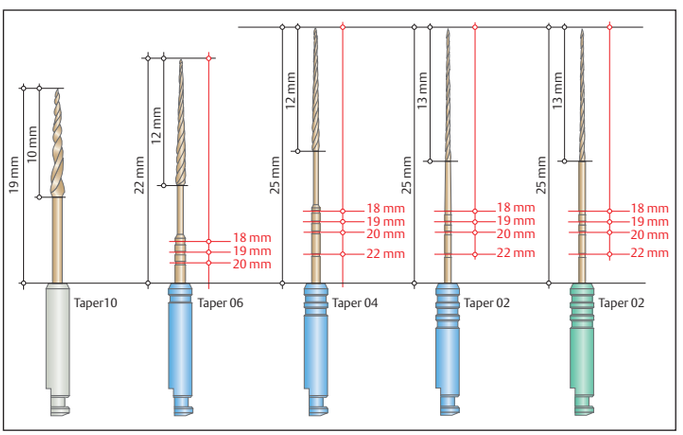
The files for coronal widening are kite-shaped in cross section with 10% taper. Their large chip space makes them a good choice as the first instrument to work with. This "pre-enlargement" provides improved tactile control and makes possible an improved insertion path with the prebent size 10 K file. This makes the introduction of other files into the canal less complicated by reducing the chances of coronal sticking of the files and permits a larger quantity of irrigating fluid to be used to improve the cleaning and antibacterial effect, thus reducing postoperative complications to a minimum.

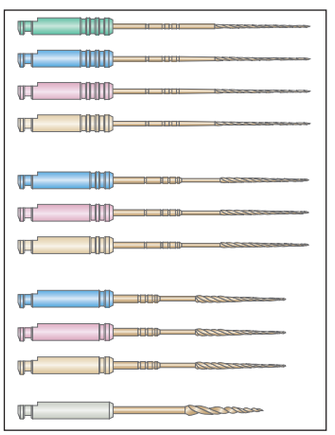
For the apical finish, instruments with a pentagonal cross-section should be used. This design aims to prevent instrument fracture; the tested torque values are the highest in comparison to all other instruments. The negative cutting angle achieves passive dentin removal and prevents excessive cutting into the root canal wall.

23.1 Principles of manufacture

Design principles of the Alpha file. The 19-mm long orifice widener exhibits a taper of 10% (.06), making the entire instrument length 22 mm; all other files are 25 mm long with a working portion of 13 mm.

Right: The color coding corresponds to ISO recommendations. The taper is indicated by notches on the instrument shaft: 2% taper file has three notches, 4% taper file has two, and 6% taper file has one notch.





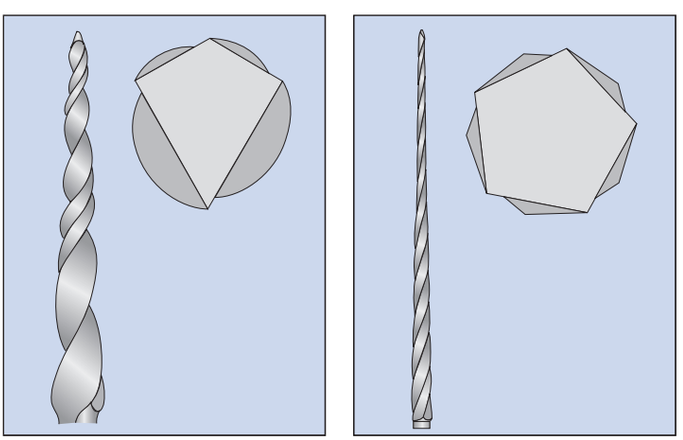
23.2 Working end and cross section

Left: Working end of the orifice widener with a large chip space for necessary dentin removal from the canal.

Left above: Kite-shaped cross section of the orifice-opening file.

Right: Working end of files with tapers of 2%, 4%, and 6%.

Right above: Pentagonal cross section of the Alpha file. This instrument cross section is designed for a high level of fracture resistance.



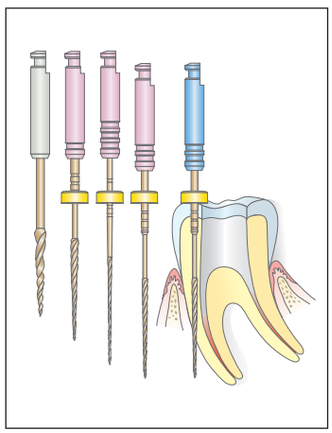
23.3 Instruments

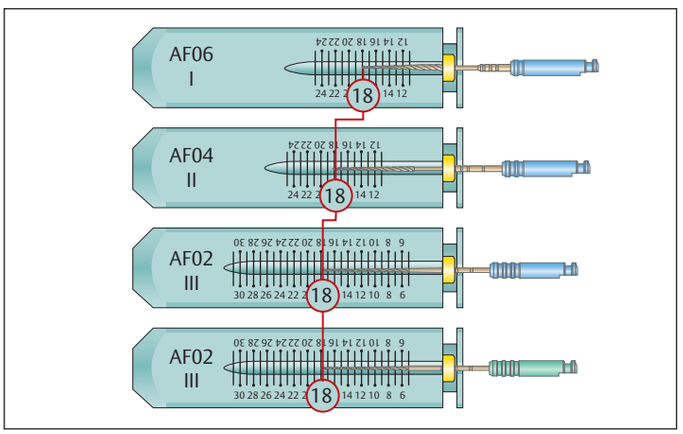
Instrument set with additional sizes indicated for larger root canals. Using the green sequence, canals are instrumented with an apical scouting file of size 20.

Right: Instruments for basic treatment of small (yellow sequence), medium (red sequence), and larger root canals (blue sequence).

All instruments are coated with a layer of titanium nitride. This process guarantees the maintenance of sharpness even following repeated sterilization (Schäfer, 2002). The speed of rotation of the orifice-widening files should not exceed 800 rpm; all other instruments are used at a speed of 250 rpm. The instrumentation is carried out using the crown-down technique with increasing taper of the instruments. Following coronal widening of the canal orifice, the initial depth is prepared with a file with 6% taper. The 4% file can be used up to 2 mm above the apex, and the 2% file is then used to the full working length.

Size selection is carried out with the apical "scouting" file: Using the size 8 file, the canal is instrumented using the yellow sequence, increasing the file size by one number at a time until the final apical opening corresponds to a size 25 file tip.

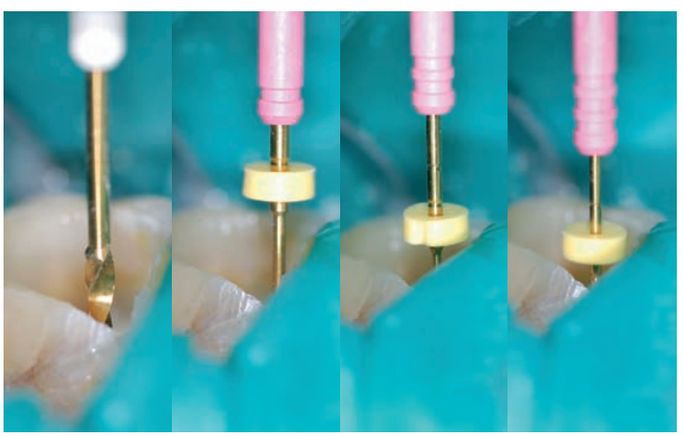




23.4 Crown-down technique

Alpha files for estimating the working length. The estimated working length is transferred to the various files, resulting in a crown-down instrumentation technique.

Left: Crown-down technique. Following coronal widening of the canal orifice, the initial depth is prepared with a file with 6% taper. The file with a taper of 4% can be used up to 2 mm above the apex; the 2% taper file is then used to the full working length.



23.5 Clinical procedure, step-by-step

Left: The procedure is initiated using the orifice-widener and instrumentation to just short of the curvature of the canal.

Middle left: Instrumentation of the middle third of the canal using a file with 6% taper.

Middle right: Instrumentation to just short of the apical foramen.

Right: Instrumentation to full working length using a file with 2% taper.

23.6 Clinical case

Left: Master-point radiograph following complete cleaning and shaping of tooth 46.

Right: Follow-up radiograph of the definitive root canal filling.

FlexMaster

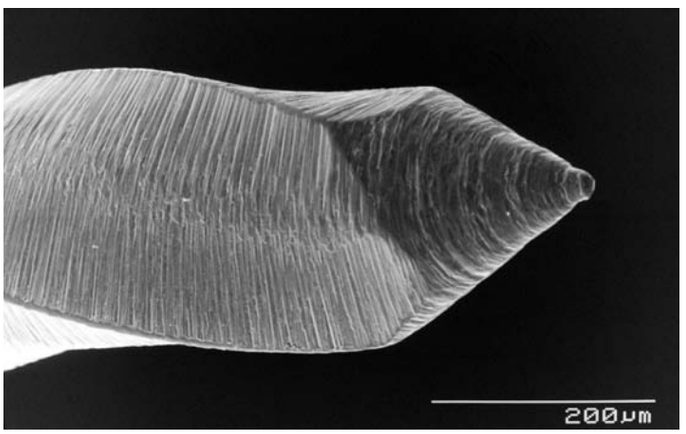
The FlexMaster system (VDW, Munich, 2000) is characterized by a large assortment of root canal instruments of various sizes (15–70) and tapers (2%, 4%, 6%). The instruments are fabricated from a 55-nitinol alloy. The convex instruments exhibit an increased resistance to torsion and therefore reduced danger of fracture within the canal.

FlexMaster instruments are used at a constant rotation speed of 150–300 rpm. The instrumentation of the root canal is carried out using the crown-down technique. As with all other nickel titanium (NiTi) systems, the FlexMaster files should only be used in a torque-controlled handpiece to avoid the danger of the file getting stuck in the canal and possibly fracturing because of torsion.

Depending on the size of the root canal, instrument manufacturers recommend a variety of file sequences for instrumentation as a guide for narrow, middle, and broad canals, which are represented by color coding in the instrument set. For example, the start of the sequence for a broad root canal involves the use of an Introfile following exposure of the root canal orifice for instrumentation of the coronal segment of the canal with a .06/30 instrument.

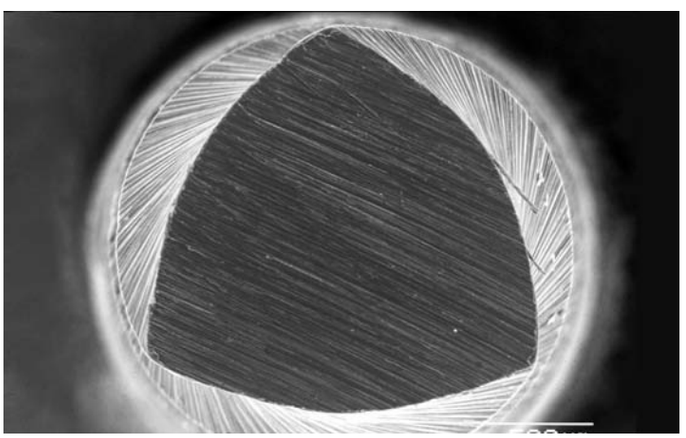
23.7 Instrument tip

Similar to the majority of current NiTi file systems, the FlexMaster instruments also have a passive, noncutting tip with rounded transition angles. In addition to tapers of .06 and .04, the FlexMaster system also includes files with .02 taper. Because of their low taper, these files make it possible to make the preparation significantly wider at the apex, up to ISO size 70 (scanning electron microscopy [SEM] ×100).



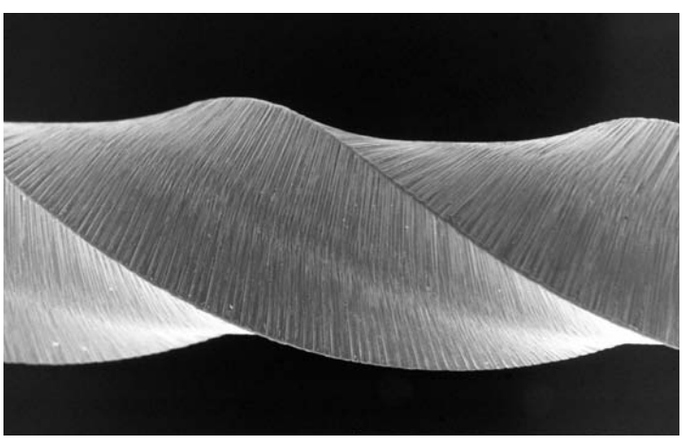
23.8 Instrument cross section

The convex triangular cross section of the FlexMaster instruments is designed to increase the resistance to torsion, therefore also reducing the risk of fracture. In contrast to instruments exhibiting a U-shaped cross section, the chip space width is relatively small with the FlexMaster files. Despite the relatively broad file cross section, these instruments possess sufficient flexibility to prepare even severely curved canals (SEM ×100).



23.9 Cutting edges

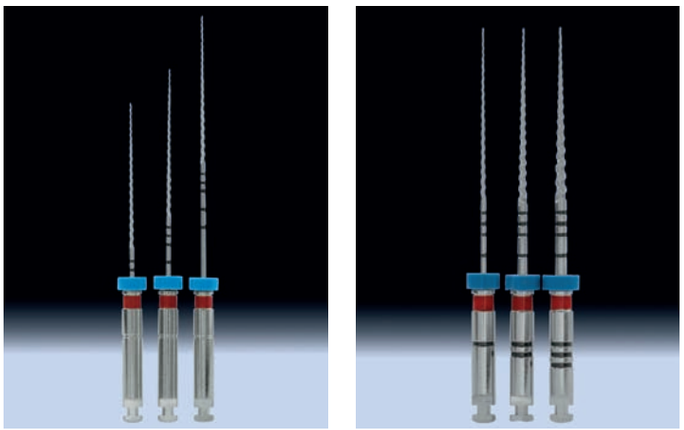
All FlexMaster instruments have three cutting edges. These files do not have broad radial lands on the lateral aspect of the cutting edges to ensure the highest possible cutting efficiency. Because the use of rotary instruments with sharp cutting edges is associated with the potential danger of "screwing" the instrument into the canal, such instruments should only be used with torque-controlled motor systems (SEM ×100).



Following the principles of the crown-down technique, files of sizes .06/25, .06/20, and .04/30 are recommended. The apical preparation is subsequently carried out to the desired size using .02 taper files.

The cleaning efficiency of FlexMaster files is universally viewed as positive (Hülsmann, 2003). However, in comparison to purely hand instrumentation, canals instrumented with the FlexMaster files exhibit a larger smear layer as well as residual debris (Schäfer, 2002).

With regard to the shaping of the root canal and to the original root canal axis, the FlexMaster system is clearly superior to conventional, manual instrumentation (Schäfer, 2002). Even narrow and severally dilacerated canals can be almost perfectly instrumented and prepared for root canal filling (Hübscher, 2003).



23.10 FlexMaster files

Left: These files are available in lengths of 21 mm, 25 mm, and 31 mm.

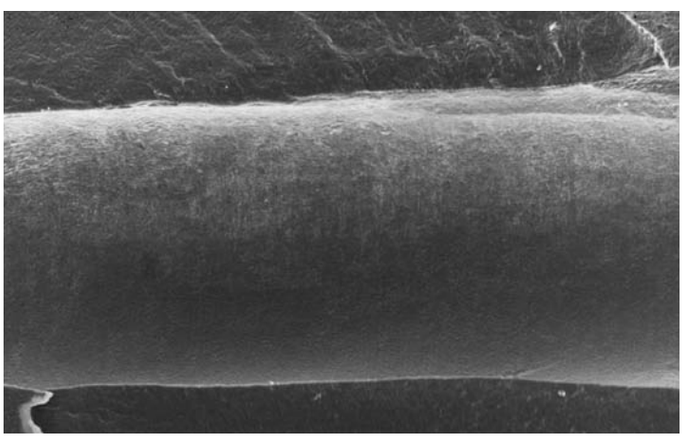
Right: The taper of each file is indicated by grooves in the shaft (1 ring = .02, 2 rings = .04, 3 rings = .06). The length of the working portion, incorporating the cutting edges, is 16 mm in all of the files.

Note the black circular markings above the cutting edges, which permit reliable determination of working length.

23.11 Preparation

Instrumentation is carried out using the crown-down technique, with decreasing file size. For the mandibular molar depicted here, a sequence for the mesial root would proceed from .06/20 to .04/30, .04/25, and .04/20. After reaching the working length, apical preparation is carried out using .02/30 files.

Instrumentation up to ISO size 30 should be the goal in every canal to ensure adequate irrigation of the prepared canal.



23.12 Prepared canal wall

This SEM image depicts a section of the canal wall in the middle segment of a root, prepared using FlexMaster instruments. This section is free of debris, the dentin appears smooth and free of gross scratches or other evidence of instrumentation. The prepared dentin surface is coated by a thin and homogeneous smear layer (SEM ×100).

K3

The rotary NiTi K3 file system (K3 RNT; Sybron-Endo, Orange, CA, USA) differs from other available systems because of its asymmetric design, which gives it extraordinary flexibility, cutting efficiency, tactile control, and fracture resistance. The K3 file system should be used clinically based on the following prerequisites:

- K3 files must be passively and gently inserted;
- each time the file is inserted only 1–2 mm of dentin should be removed;
- irrigation and recapitulation should follow each K3 file insertion.

After traversing the full length of the canal and manual widening with a K file of at least size 15, the K3 file system is used with the crown-down technique.

The variety of file types in the K3 file system is large: for coronal enlargement, files with a taper of .08, .10, and .12 and a tip diameter of size 25 are available. For canal shaping, files of taper .02 and sizes 15–45 as well as tapers of .04 and .06 in sizes 15–60 are available. Corresponding gutta-percha points of taper .04 and .06 in sizes 15–45 complete the K3 set-up.

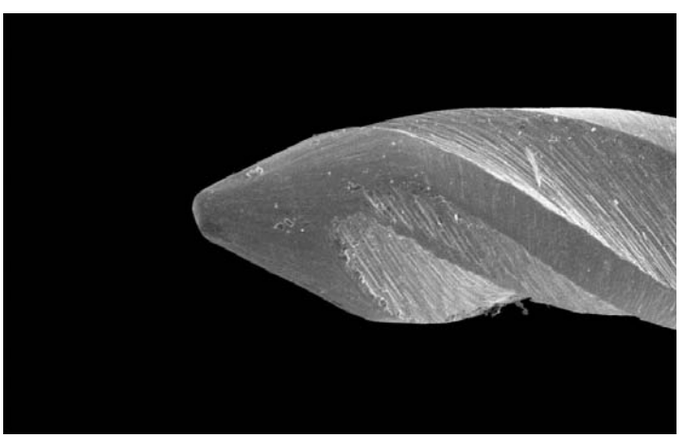
23.13 The K3 files

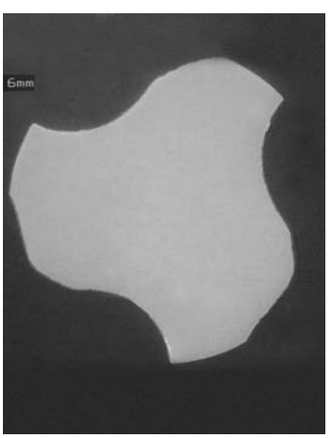
The NiTi files from Kerr (SybronEndo) are available in a broad range of tapers and diameters for all root canal configurations.

23.14 SEM images

The K3 files have a broad cutting area, which is also tapered. The cutting edges merge smoothly at the precisely formed torpedo-shaped, round edge file tip.

Right: This cross-sectional SEM view reveals the complex cutting geometry with its U-shaped cut-outs.

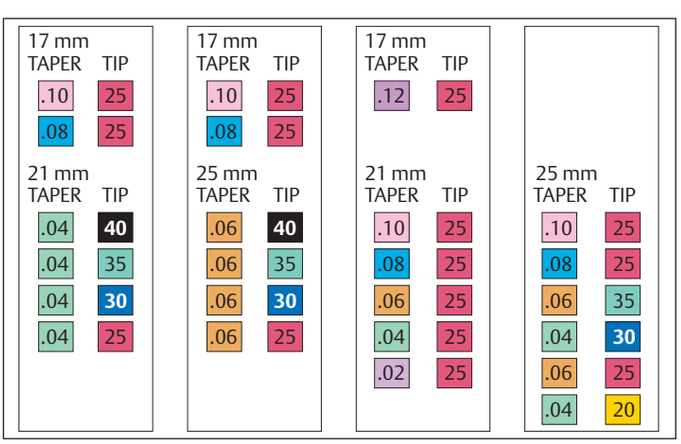




23.15 File sequence

Depending on canal shape and length, instrumentation using NiTi files requires selection from a variety of file sequences. The manufacturer's guidelines should be adhered to in this regard.

The Procedure Pack is used with the crown-down technique, .04 taper and 21 mm (left), .06 and 25 mm (middle, left). In the G-Pack only the taper varies (middle, right). In the VTVT Pack, tip diameter and taper vary alternately (right).

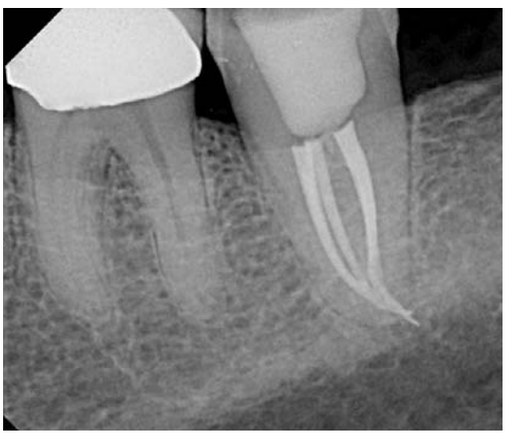


The manufacturer recommends three file sequences:

- The Procedure Pack: .10/25 and .08/25 should be used for enlarging the access cavity, and sizes 40–25 (taper .04/.06) for the crown-down preparation.
- With the G-Pack, the tip diameter remains constant at size 25, and the taper varies from .12 to .02.
- With the VTVT Pack there is a change in taper (variable taper) and tip diameter (variable tip), which is generally regarded today as an adequate and fracture-reducing clinical model.

K3 has to date been reported in 33 publications. K3 files are much more resistant to cyclic fatigue than ProFile (Yao et al., 2006) in the 40/.04 and 40/.06 sizes , and also more resistant to fracture (Ankrum et al., 2004 [although not statistically significant], Troian et al., 2006). On the basis of its effectiveness in removal of gutta-percha, the K3 file system has been recommended for endodontic retreatment (Masiero et al., 2005; de Oliveira et al., 2006):

K3 files also help to precisely prepare the apical anatomy in complex root curvatures and minimize compression of the smear layer (Yoshimine et al., 2005; Kum et al., 2006).



23.16 Clinical case I

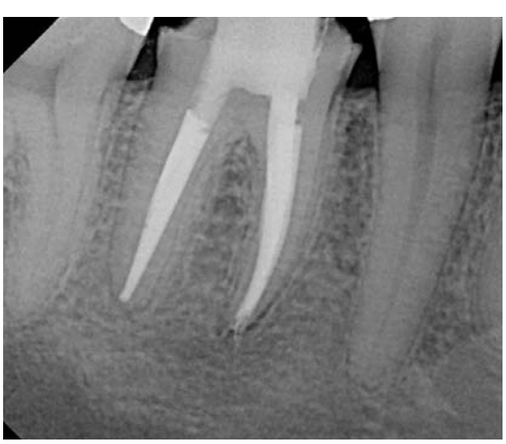
Left: Preoperative radiograph of a mandibular molar showing a broad coronal pulp and "normal" root canals within a fused root situation.

Right: In the apical third, the three root canals are severely curved, and the distal canal has a double-S shape. However, a perfect root canal filling with preservation tooth substance was accomplished.

23.17 Clinical case II

Left: Preoperative radiograph of the maxillary second molar showing an almost 90° dilaceration of the mesial root.

Right: In order to achieve straight-line access, considerable tooth substance had to be sacrificed. This radiographic view of the dense root canal filling is testament to the success of the clinical procedure in the severely dilacerated canal.



23.18 Clinical case III

Left: A previous endodontic "attempt" resulted in an inadequate root canal filling. The radiograph shows persistence of periapical inflammation, and the patient continued to experience pain and discomfort.

Right: Following endodontic retreatment of the tooth, with dense, warm vertical compaction of Resilon, a tight seal was obtained resulting in complete healing and resolution of the apical lesions.

LightSpeed

LightSpeed instruments are made of NiTi indicated for root canal instrumentation. They were developed by Wiley and Senia and entered the commercial dental market in 1993. A classic LightSpeed set consists of 22 instruments of ISO sizes 20–100. Between sizes 20 and 70, half-sizes are also provided (22.5, 27.5–65). The root canal is instrumented at a speed of 2000 rpm.

In contrast to the conventional endodontic instruments, which have a 16-mm long working section, LightSpeed files have a long, thin shaft and a short working end with a blunt tip.

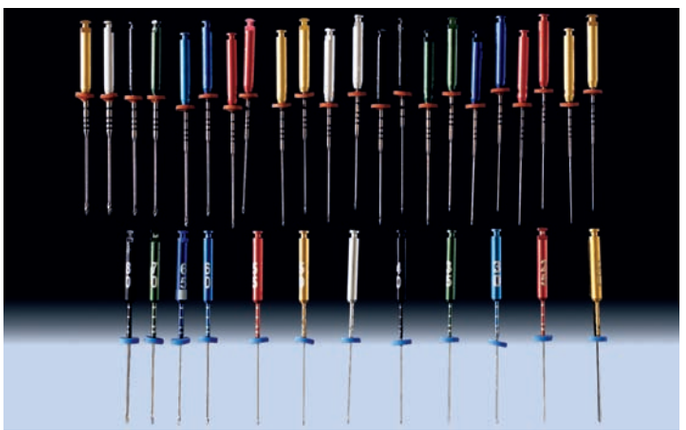
The length of the working section depends on the ISO size. For example, the size 20 file has a 0.25-mm long cutting section whereas the size 100 file has a cutting section that is 1.75 mm long.

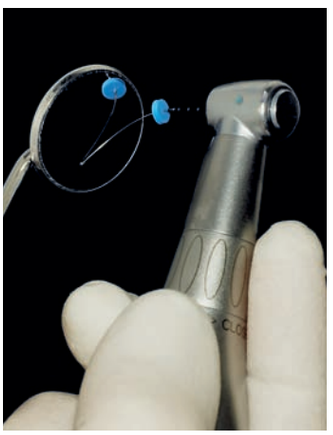
During root canal preparation, the noncutting tip points away from the canal wall and the file is thus retained in a more central position. Because of the high flexibility of the instrument shaft, the danger of "straightening" the canal is significantly reduced (Glosson et al., 1995; Shadid et al., 1998; Hülsmann et al., 2003).

23.19 LightSpeed instruments

The 22 LightSpeed files are color coded according to the ISO norm. The half-sizes are marked with a point toward the head end of the handle. Each of the 12 instruments of an LSX instrument set has the appropriate ISO size on the handle. Special sizes up to 140 are available in LightSpeed and LSX files.

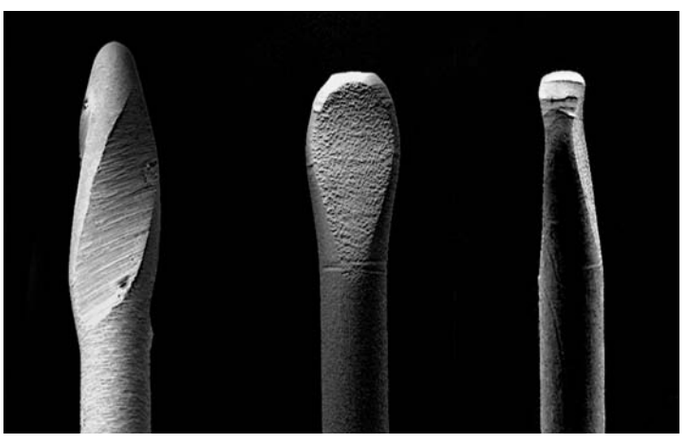
Right: Because of the very thin shaft, LS and LSX instruments are extremely flexible.





23.20 Geometry of the working section

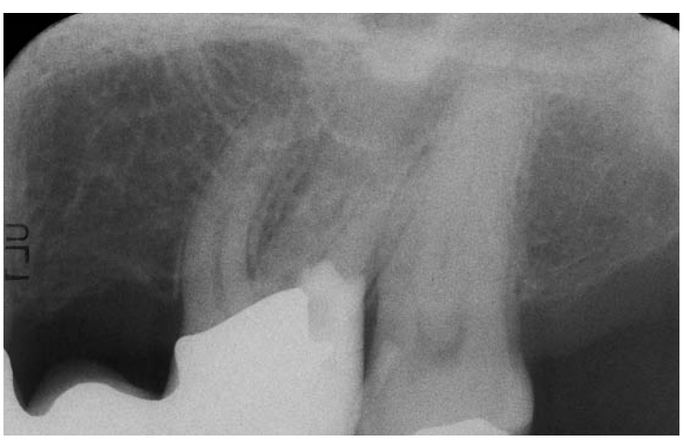
SEM of LS file size 35 and an LSX file size 35 seen from the front and the side. The working head of the LS has U-shaped grooves separated from each other by radial lands (left). The working end of the LSX (middle and right) is in contrast flat and spade-shaped and has only two radial lands (original magnification ×60, 15 kV).



23.21 Initial radiograph

Tooth 26 was clinically symptomatic and the radiograph revealed apical periodontitis in relation to the palatal root. The canal orifices of the disto-buccal and palatal root canals were completely obliterated.

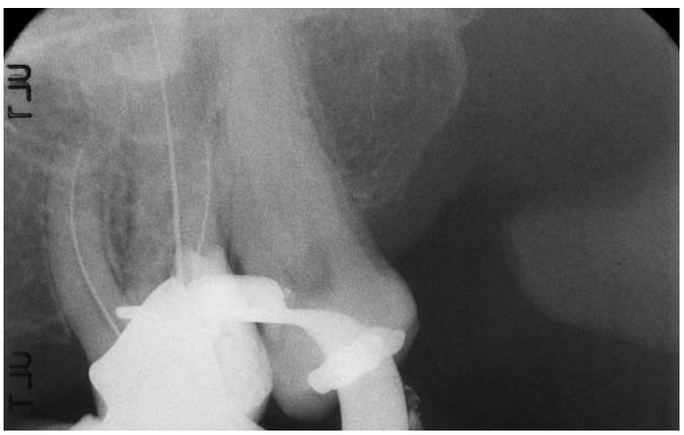
Right: Mesiodistal and bucco-palatal views of an extracted maxillary first premolar.



The major advantage of the LightSpeed system is gentle coronal instrumentation and minimal removal of hard tissue. Both of these are critical factors for posttreatment ability of the tooth to resist fracture (Lang et al., 2006). A disadvantage is the very large number of instruments required.

Since mid-2006 the LightSpeed eXtra (LSX) system has been available on the commercial market; it will eventually replace the LS system. LSX consists of only 12 instruments of sizes 20–80. The new instruments are not manufactured using the grinding process because this mechanical process can lead to imperfections of the surface (Eggert et al., 1999), which can later lead to instrument fracture.

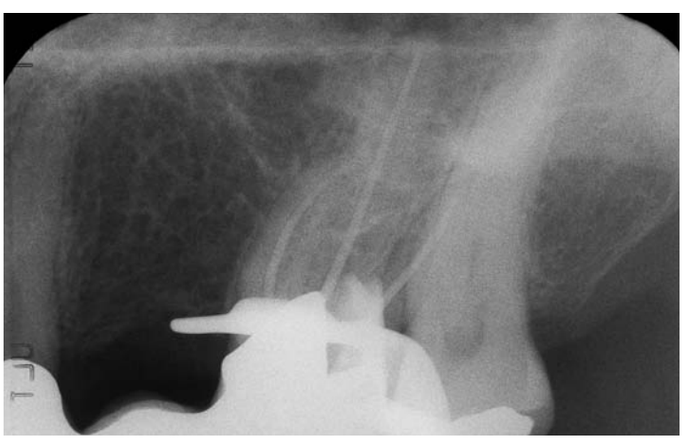
LSX files are punched out of raw stock. The head of the instrument has a short and flat working area with two radial lands and a blunt tip. The long, thin instrument shaft of the LightSpeed files is unchanged in the LSX system. The recommendation is to utilize these instruments at 2500–3000 rpm and a higher level of torque. These modifications of the LightSpeed system have been designed to simplify the technique and reduce the risk of instrument fracture. The advantages of LS with regard to canal straightening and loss of working length remain unchanged (Iqbal et al., 2007).



23.22 Measurement radiograph

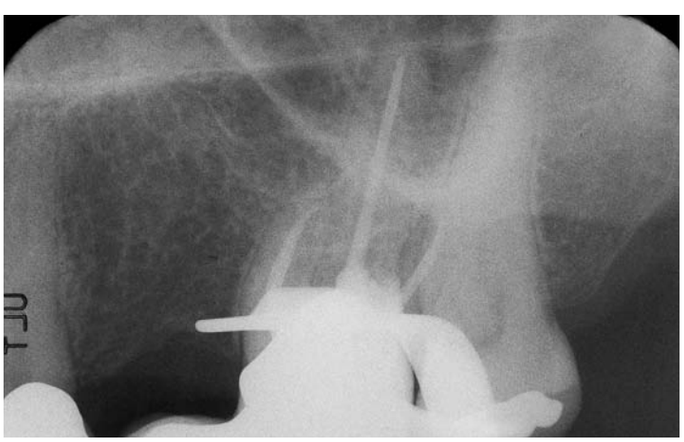
The working length was determined using size 15 K files. Thereafter, the canals were instrumented using LS files up to size 20, until the apical stop was prepared. Note that no size should be skipped during the preparation of the root canal. The stepback preparation technique was used, with shortening of the working length by 1 mm with each subsequent file.

Left: Determination of working length using size 15 K files.



23.23 Master point radiograph

Master point radiograph following definitive canal instrumentation and placement of a calcium-hydroxide dressing.



23.24 Radiographic follow-up

Obturation of the root canals using lateral compaction.

Left: Lateral compaction of the root canals. Despite stepback preparation up to size 80 and 100, both the canals are still quite narrow in the coronal segments.
The preparation was carried out to save as much dentin as possible, to prevent subsequent fracture of the tooth.

Mtwo

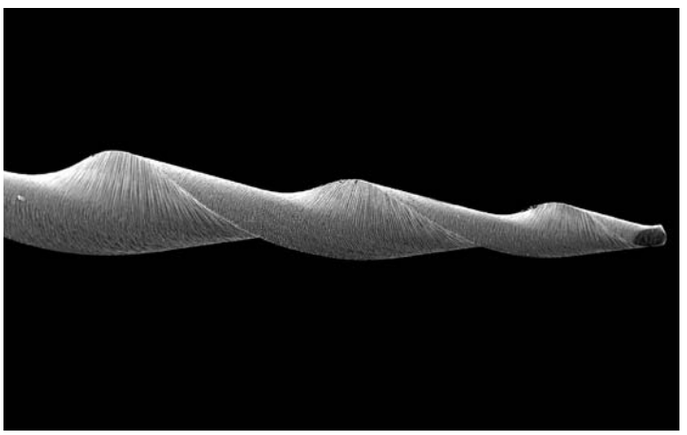
The Mtwo system (VDW, Munich, Germany) has eight instruments of ISO sizes 10–40 with taper ranging from 4% to 7%. A significant characteristic of the instrument is the presence of two cutting edges with long and almost vertical spirals. Mtwo files, similar to FlexMaster files, are fabricated from 55-nitinol alloy. They are commercially available in lengths of 21, 25, and 31 mm.

In contrast to the FlexMaster files, the Mtwo system files have a relatively small instrument core and a larger chip space. The core size increases with growing file diameter, as the distance between the two cutting edges increases from the instrument tip toward the shaft. This type of endodontic instrument geometry is designed to provide a higher level of debris transport out of the canal, while reducing the danger of "screw-in" tendency.

Root canal preparation using the Mtwo files is carried out using the so-called "single-length" technique. Following enlargement of the root canal orifice and creation of a glide path using an ISO size 10 or 15 K file, the Mtwo files can be used for complete and thorough preparation of the root canal. The use of these files within the canal for instrumentation thus becomes a passive procedure.

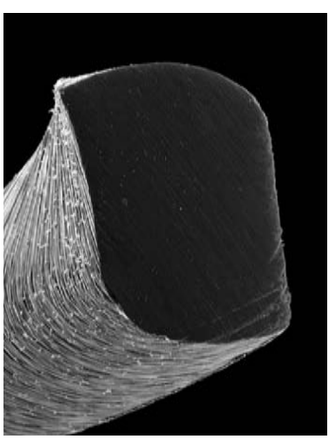
23.25 Instrument design

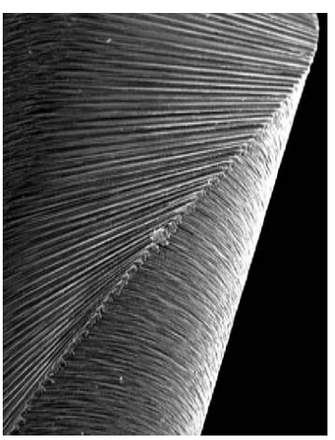
In contrast to most other NiTi instruments, the Mtwo files have only two cutting edges, in the form of a double helix, starting from the instrument tip up to the shaft of the working segment. The distance between the cutting edges increases from the file tip upward. The file has a passive, noncutting tip (SEM ×30).



23.26 Cutting edges and instrument cross section

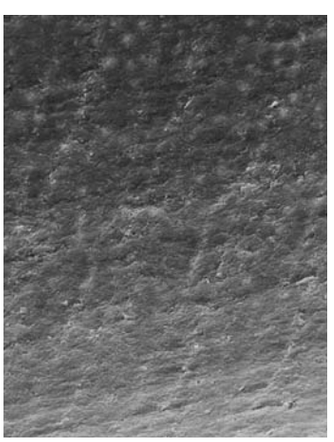
The relatively small S-shaped cross-sectional area (left) and the two cutting edges (right) are designed to give the instrument higher flexibility. With the increasing distance between the cutting edges upward to the shaft, the chip space also grows in accordance with increasing instrument diameter; this ensures good purchase of and consistent removal of dentin in the coronal direction (SEM ×100).

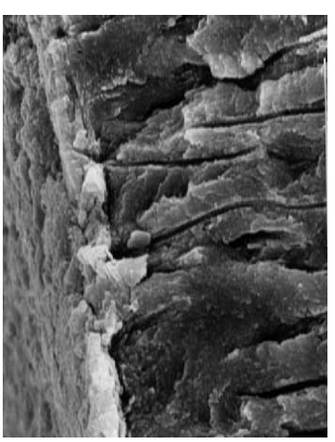




23.27 Prepared root canal wall

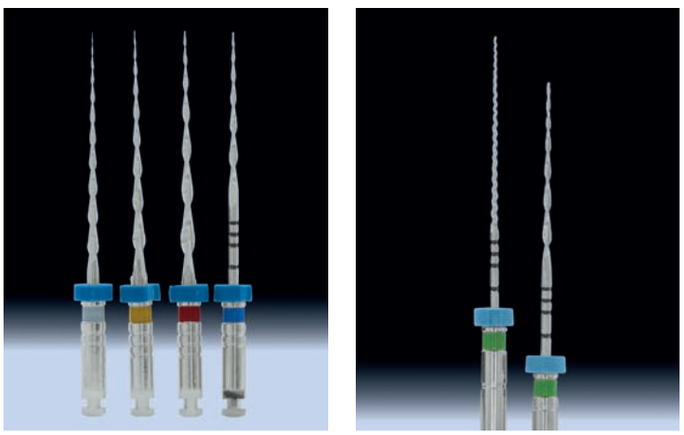
This canal was prepared using Mtwo files and the single-length technique; in this large segment of the root canal note that the surface is relatively smooth and clean with a thin and homogeneous smear layer. These images are of the middle third of the canal. The highest level of cleaning efficiency achieved with Mtwo files is in the coronal and middle thirds of the canal (SEM left ×500, right ×1000).





Through the use of lateral movements, it is possible to widen the coronal third of the root canal to a larger taper, and this simplifies canal filling with a thermoplastic material. The recommended speed of rotation is between 280 rpm and 350 rpm. Mtwo files should be used with a torque-controlled handpiece on the dental unit or an endodontic motor drive.

The cleaning efficiency of the Mtwo system is comparable with other NiTi systems (Foschi, 2004). While the coronal and middle thirds of the canal are free of debris, the apical third has obvious smear layer debris as well as noninstrumented regions. The shaping of prepared root canals with regard to taper and reduced transportion of the original canal axis have been described as very good (Sonntag, 2005).



23.28 Mtwo instruments

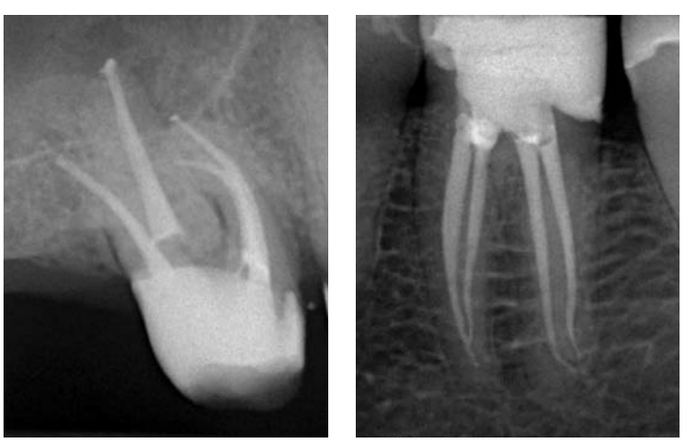
Left: Files of 25 and 31 mm overall length are available with the choice of 16- or 21-mm long working sections. Files with the shorter working sections are marked at 18, 19, 20, and 22 mm.

Right: The taper of the instruments is indicated by engraved rings on the instrument shaft. The 11-mm shaft of the Mtwo file (right) is significantly shorter than that of a FlexMaster file (left).

23.29 Instrument sequence

The basic sequence consists of: 10/.04, 15/.05, 20/.06, and 25/.06. All instruments are used to the full working length (single-length technique). Apical expansion to the desired size is accomplished using instruments 30/.05, 35/.04 and 40/.04.

A special significance of instrument 25/.07: it can be used to create an increased taper for thermoplastic root canal fillings.



23.30 Canal preparation

Both teeth were prepared using the single-length technique, in which each instrument is used to the full working length. The mandibular molar (right) was instrumented to size 30/.05, with the maxillary molar (left). Following completion of the apical preparation to 35/.04 to 40/.04, the 25/.07 instrument was then used to create greater taper.

ProFile

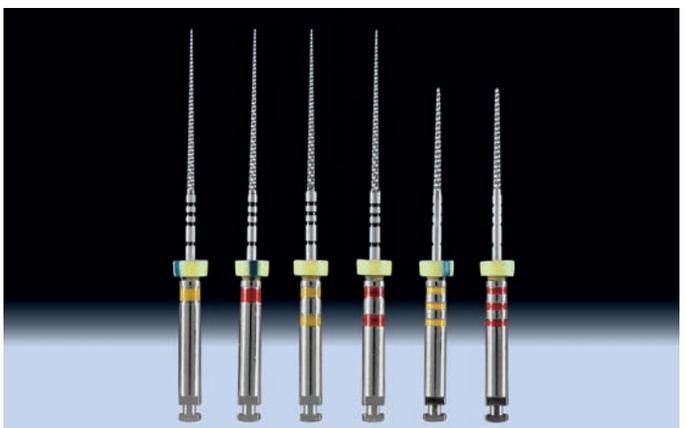
The ProFile system (Maillefer, Ballaigues, Switzerland) was introduced in 1992 by Ben Johnson (Lloyd, 2005). The original concept paved the way for numerous rotary NiTi instruments. In retrospect, this system can be viewed as the "break-through" engine-driven NiTi endodontic system, which led to the development of a large number and variety of such instruments and their worldwide popularization. Up until that time, due to the high level of sensitivity required, only a few experienced clinicians were able to master the techniques of shaping of root canal systems based on the postulates of Schilder (1967) using ISO-norm hand instruments.

Engine-driven rotary NiTi instruments made it possible for a much larger number of clinicians to shape the canals in a more consistent and predictable manner, even in challenging endodontic situations. The ProFile system initiated a remarkable change in the discipline of endodontology in a way that had not occurred for many decades.

Due to its early introduction into the marketplace, and its current significant position, ProFile is, until now, the most studied rotary NiTi system and it remains the gold standard against which all other systems are analyzed (Lloyd, 2005).

23.31 Taper

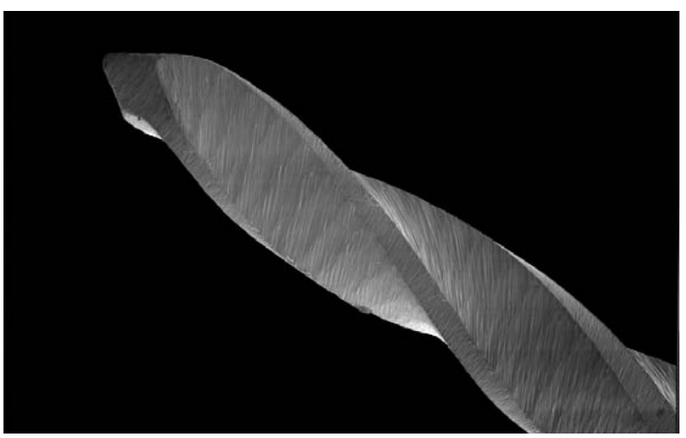
The ProFile system is available with different file tapers. A 4% taper is indicated by a one-color ring, a 6% taper with two-color rings. The orifice-shaping instruments (three-color rings) are used for initial coronal widening.

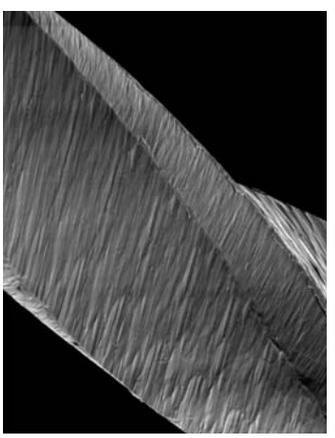


23.32 Cutting edges and tips

The instruments have a noncutting tip. The U-shaped cross section provides high flexibility and a large chip space to aid the removal of dentin debris from the root canal.

Right: The flattened widening of the cutting edges (called radial lands) are designed to ensure that the file remains centered within the root canal without being screwed in.





23.33 Step-down technique

When using the ProFile instruments in the step-down technique, even severely curved root canals can be instrumented to the apical diameter of size 40 distally and size 35 mesially with a 6% taper.

The Series 29 system was the first commercially marketed rotary NiTi system. In these files, the tip diameter increases by 29.4%, which does not conform with ISO specifications, resulting in a more gradual increase in diameter of the smaller instruments and a more pronounced increase in the diameter of the larger instruments. This reduces the number of instruments necessary in an endodontic "kit."

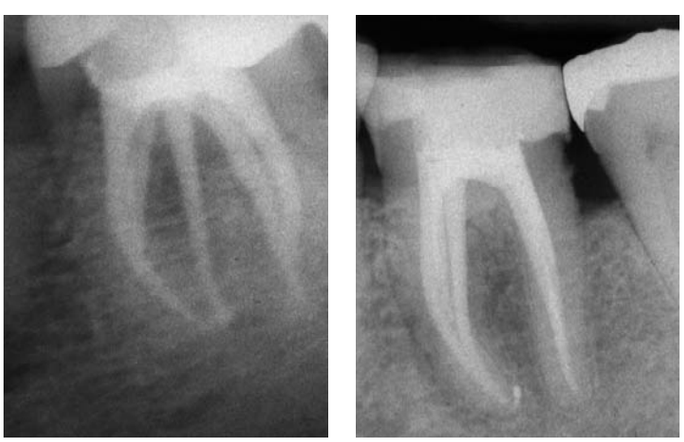
Subsequently, instruments with conventional ISO diameters were introduced. The product line has been continuously enhanced with files with a 2% and 6% taper as well as instruments for initial coronal enlargement (orifice shapers).

The recommended clinical procedure is a basic crown-down technique. As an alternative, especially in difficult and severely curved canals, a step-down technique is recommended. The files should be used with picking movements within the root canal at the recommended speed of 150–300 rpm.

23.34 Clinical case I

Left: Deep caries on tooth 26 necessitated endodontic therapy.

Right: ProFile instruments of size 35/.06 in the three buccal canals and 60/.04 in the palatal canal were used for maximal apical instrumentation.



23.35 Clinical case II

Left: Only an extremely eccentric radiographic projection revealed the five root canals in the nonvital tooth 36.

Right: ProFile instruments up to size 35/.06 were used to instrument the canal using a step-down technique.

23.36 Clinical case III

Left: Radiograph of tooth 46 showing an inadequate ceramic restoration and the necessity for endodontic therapy.

Right: The use of ProFile instruments in a hybrid concept for final shaping of the apical third of the root canals allowed a continuously tapered preparation utilizing up to 35./06 and 40./06 instruments.

ProSystem GT

GT rotary files (Dentsply Maillefer, Ballaigues, Switzerland) have been commercially available since 1999. The goal of inventor Stephen Buchanan was a reduction in the number of files required in a typical clinical set. So initially the ProSystem GT set contained only one tip diameter of size 20, with tapers of 6%, 8%, 10%, and 12%, and three GT accessory files (size 35, 50, and 70), each with12% taper. The maximum diameter corresponds to size 100, so that the length of the cutting edges is progressively reduced.

Following debate concerning the excessively small apical instrumentation, files of sizes 30 and 40 were added and the 12% taper was limited to the accessory sizes. The complete ProSystem GT system now contains hand files, paper points, gutta-percha points, Thermafil points, and glass fiber points.

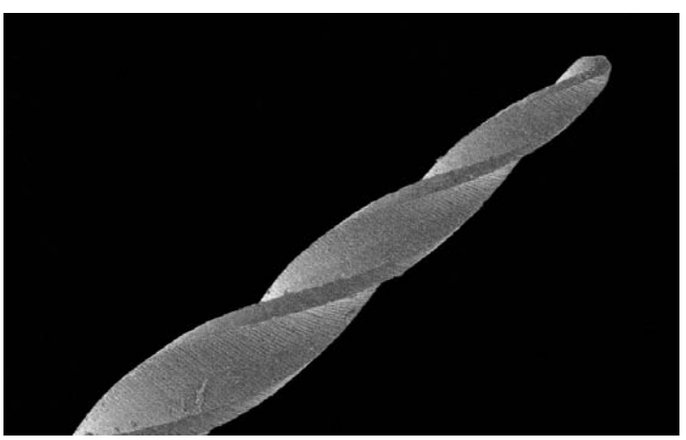
The ProSystem GT today has a special status in that the individual instruments vary less with regard to tip diameter but much more with regard to taper. The tip is passive and rounded, while the cutting edges are somewhat flattened with progressive increase in chip space, so that the movement of the file within the canal is protected, with infrequent transportation, and the screwing effect is reduced. The radial lands in the GT files make it a passive cutting system.

23.37 ProSystem GT

Left: The original GT files had four basic types with tip diameter of size 20. Today these files are available with tapers of 4%, 6%, 8%, and 10%.

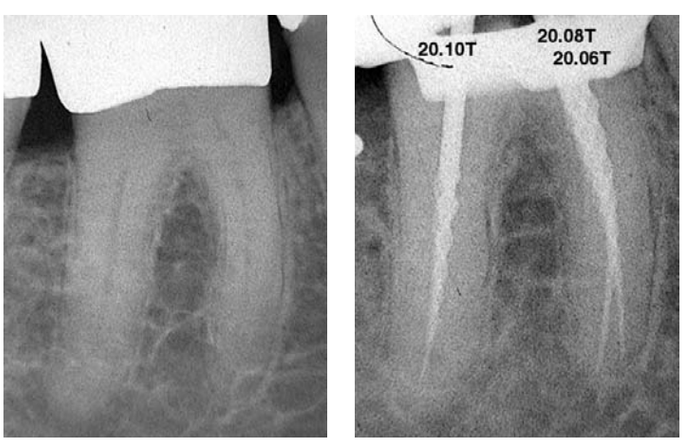
Middle: The GT files of Series 30 have a tip diameter of size 30.

Right: The GT files of Series 40 have a tip diameter of size 40.



23.38 SEM of a GT file

The design characteristics of GT files on SEM: The tip is very elegant and precisely rounded. The radial lands become progressively wider. The chip space is quite generous.



23.39 Clinical case

Left: The diagnostic radiograph shows calcification of the mesial canal orifice, and even greater calcification distally (Suter, 1999).

Right: After localization of the canal orifices using the clinical microscope and stepwise widening of the orifices, it was possible to take a radiographic image in which three GT files size 20/.06, .08, and .10 were inserted precisely up to the apical end point (Suter, 1999).

In the now 70 studies of the GT system, numerous aspects of the system have been investigated. The original form and arrangement of cutting edges resulted in a very low level of canal straightening, and reduced clinical working time because of the high taper (Gülzow et al., 2005). GT files resist deformation during canal instrumentation better than ProFile or ProTaper files, exhibiting signs of deformation before instrument fracture (Guilford et al., 2005). The introduction of the larger diameter was deemed favorable in one study, which demonstrated improved cleaning with the use of size 30 and size 40 files (Albrecht et al., 2004).

The high taper of the ProSystem GT files can certainly lead to weakening of the root, which cannot be completely compensated through use of a sealer (e.g., AH Plus) (Zandbiglari et al., 2006). Because of the passive cutting mechanism, root canal retreatment requires more time clinically than with use of FlexMaster or ProTaper, which have sharp cutting edges (Hülsmann and Bluhm, 2004). While ProTaper and eucalyptol provide the most rapid retreatment method, GT files even in combination with eucalyptol provide the least efficient and most time-consuming clinical technique for retreatment (Hülsmann and Bluhm, 2004).

23.40 Canal obturation post

Left and middle: Eccentric and orthoradial projections following root canal filling with lateral compaction and AH Plus sealer show a homogenous filling in very well shaped root canals with adequate dimensions.

Right: Because of the extensive destruction of the tooth crown, a metal post was inserted into the distal canal (Unimetric screw).

23.41 Large apical lesion and perforation

Left: Preoperatively, tooth 46 has a prosthetic crown restoration as well as large periapical lesions of endodontic origin in relation to both roots.

Right: After removal of the crown, a perforation was observed in the furcation area, created during a previous endodontic attempt to locate the canal orifices. This perforation was closed using MTA, under the microscope.

23.42 Root canal filling

Left: The radiograph reveals good positioning of the master point.

Right: Following warm vertical compaction, the radiograph depicts a homogeneous filling as well as obturation of a large lateral canal in the mesial root.

ProTaper

The ProTaper files (PT; Dentsply Maillefer, Ballaigues, Switzerland) have been available since 2001. The inventors/developers Machtou (Paris, France), Ruddle (Santa Barbara, CA, USA), and West (Tacoma, WA, USA) strived for a reduction to only six files in a set and an entirely new design. The file system was designed to enable the clinician to create uniformly tapered shapes in anatomically difficult or severely curved canals. Additional mobility within the oral cavity was achieved by a 15% reduction in the shaft length (13 mm instead of 15.34 mm). With working lengths of 21 mm, 25 mm, and 31 mm, the ProTaper files are appropriate for endodontic treatment of teeth with variable root lengths.

Built on a convex triangular profile with sharp cutting edges, the three shaping files SX, S1, and S2 have *multiple taper* (SX: 3.5%–19%, S1: 2%–11%, S2: 4%–11.5%). The shape vaguely resembles the Eiffel Tower and permits rapid and efficient progress during the root canal preparation.

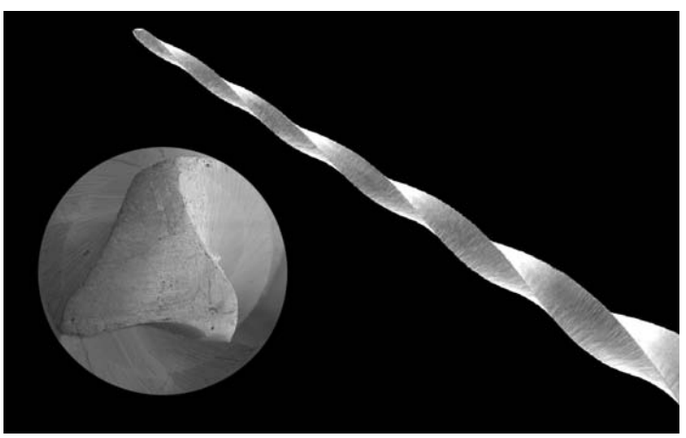
The three finishing files (F1–F3) correspond to the ISO standard with regard to tip diameters of size 20, 25, and 30, and exhibit *reverse taper*: The first 3 mm has a taper of 7%, 8%, and 9% and thereafter the taper is 5.5% (F1 and F2) and 5% (F3).

23.43 ProTaper

The original ProTaper system consisted of a set of six files (SX, S1, S2, F1, F2, and F3). SX (size 19) is somewhat shorter and has no color coding on the shaft. The other five files are in accord with the ISO color coding, beginning with violet (size 17) through white (size 20), yellow (size 20), and red (size 25), to blue (size 30). Thus, only the three F files correspond in tip diameter to the ISO color coding and attendant ISO sizes.

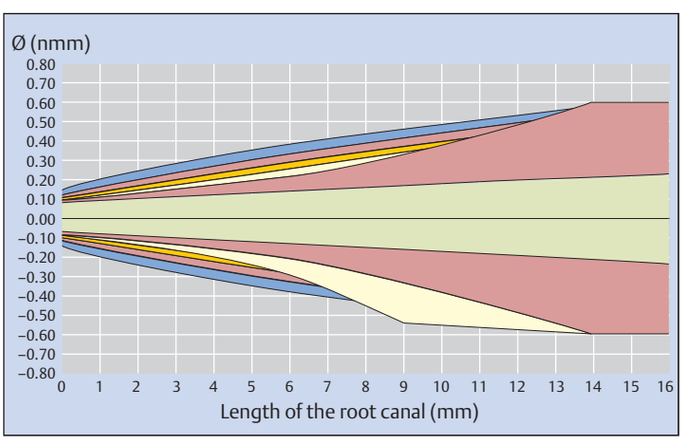
23.44 SEM image

In this high-magnification image, the sharp cutting edges, increasing taper, and rounded tip of a ProTaper file are clearly seen. The first five files have a convex triangular cross section. To improve flexibility F3 has a reduced core.



23.45 Dimension of the ProTaper

The tip diameter and the overall appearance and shape of the ProTaper files are depicted here graphically to provide an overview of the canal shapes achievable with this system.



The unconventional design encouraged investigators to carry out over 50 individual studies of these instruments. In a mathematical model, ProFile exhibited more elasticity but ProTaper files showed improved stress distribution (Berruti et al., 2003). ProTaper instruments were highly effective in narrow root canals (Peters et al., 2003). The progressive tapering proved to be less influenced by curvatures in the mid-root area in comparison to the constant taper of K3, thus allowing a well-centered apical preparation with, however, a tendency for coronal transportation in the direction of the furcation (Bergmanns et al., 2003).

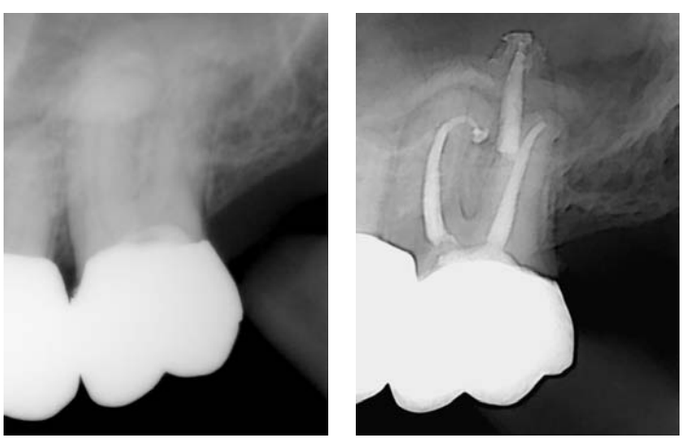
SEM studies revealed that smear layer removal using ProTaper files was comparable with that with RaCe instruments, but debris removal was poorer. The clinical time required for root canal preparation using the ProTaper system was either similar or clearly less than that with RaCe (Schäfer and Vlassis, 2004; Paqué et al., 2005).

The removal of gutta-percha fillings proved efficient and time-effective using ProTaper files (Hülsmann and Blum, 2004). Some authors are of the opinion that use of the ProTaper system by an experienced clinician reduces the danger of instrument fracture in comparison with use of an endodontic motor (Yared et al., 2003).

23.46 Clinical case I

Left: Preoperative radiograph of a mandibular molar. The mesial root has an S-shaped dilaceration.

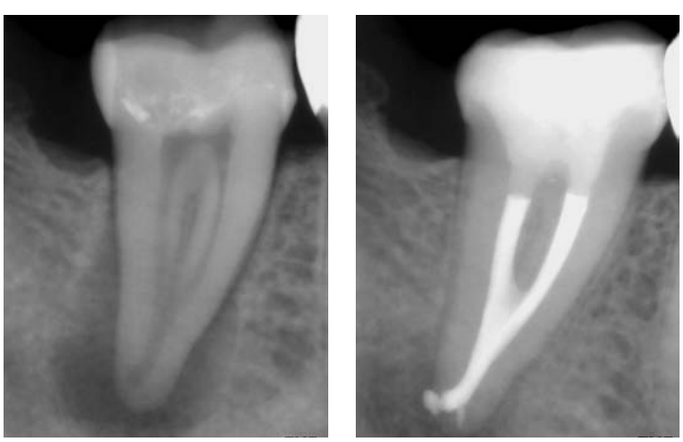
Right: Following preparation with ProTaper files, the root canal filling was accomplished using warm vertical compaction. The S-shaped curve has been extremely well obturated.



23.47 Clinical case II

Left: Preoperative radiograph of a maxillary molar. Severely curved and calcified root canals suggest difficulties during preparation.

Right: On the mesial aspect, the root canal exhibits extreme curvature. Warm vertical compaction will result in a homogeneous root canal filling after careful and complete preparation.



23.48 Clinical case III

Left: The mandibular molar has a large apical radiolucency. The root canals are confluent in the apical third of the root.

Right: While maintaining the original canal shape and form, a tapered and harmonious canal shape was created and subsequently filled using the warm vertical compaction technique (courtesy of T. Clauder).

ProTaper: Clinical Application

The first instrument to be used after scouting the root canal to a maximum two-thirds of the estimated working length is S1. During the insertion of S1, a "brushing" motion should be used to reposition the canal access away from "danger zones" in furcal regions.

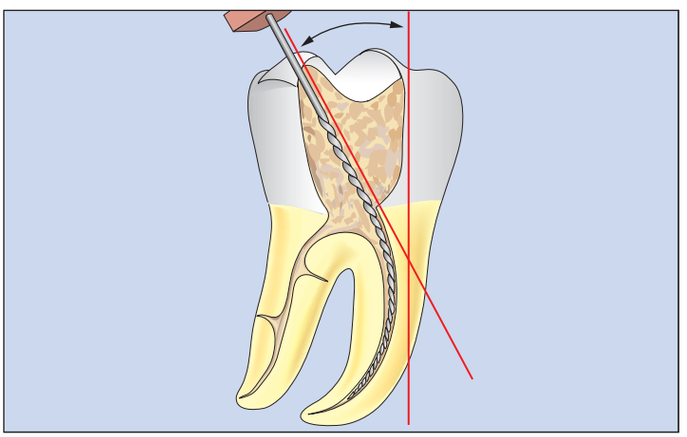
The next file used for coronal shaping is SX. SX serves as a replacement for Gates-Glidden drills, and allows perfect preparation of the coronal segment of the root canal. The repeated use of SX permits deeper penetration of the instrument and the removal of overhanging dentin walls.

Following the initial use of the crown-down technique, the working length is determined and apical patency established by inserting a size 10 K file passively into the root canal system. The working length must always be determined electronically and confirmed with properly adjusted radiographic exposure.

In most cases it is prudent to establish a reproducible glide path using hand instruments up to ISO sizes 15 or 20 to reduce the risk of instrument fracture. Once the glide path has been prepared by K files, S1 and S2 are used with a "brushing" motion to the full canal length.

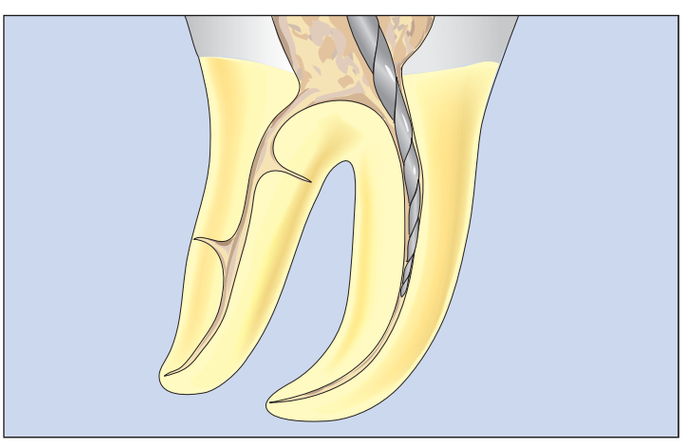
23.49 ProTaper, step I

The first step following careful preparation of the access cavity is probing and scouting of the canal using a size 10 K file up to about two-thirds of the anticipated working length.



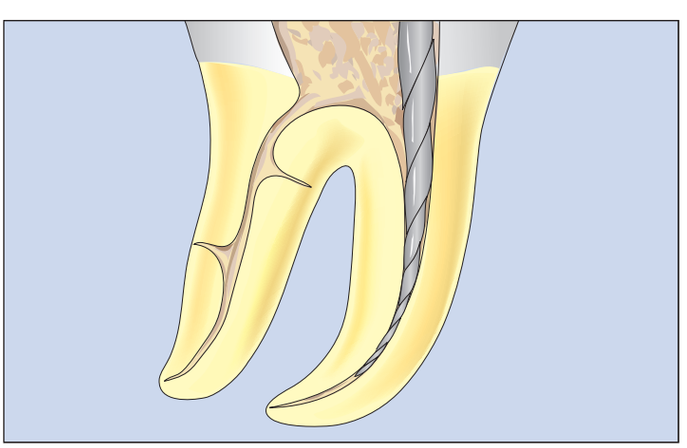
23.50 ProTaper, step II

After insertion of S2 to two-thirds of the working length, the SX file is used for coronal shaping in a brushing motion against the canal walls. The instrument is inserted less deeply than the previous hand instrument and is used to reposition the canal access away from the "danger zones" in the furcation regions.



23.51 ProTaper, step III

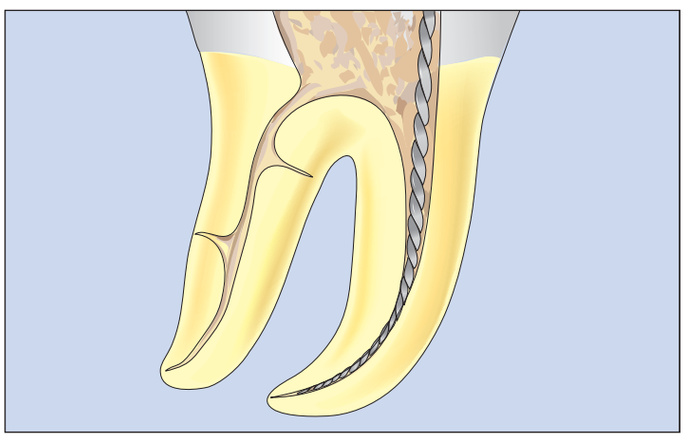
The SX file is rotated into the canal. If mild resistance is encountered, the file should be removed, using the "brushing" technique.
The next insertion permits deeper penetration of the instrument as well as the removal of any overhanging dentin walls.



The apical preparation is completed using the finishing files. F1, which has an instrument tip diameter that is identical to S2, can now be used to full working length. The apical diameter is measured using a 20 K file, which must passively fit to the full working length, to confirm that the diameter of the foramen is equivalent to size 20 or is larger.

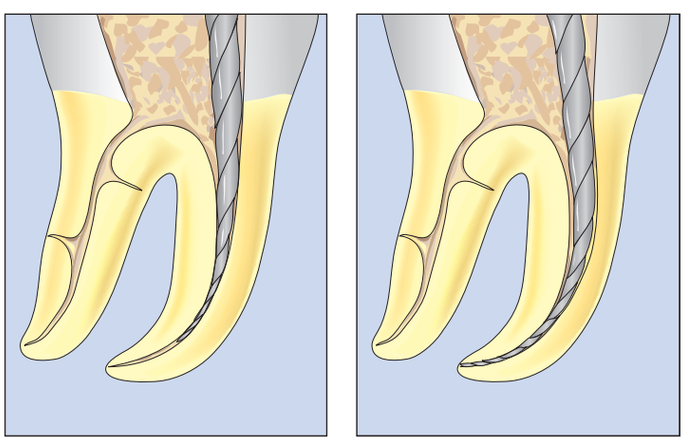
When the file binds snugly at the apical end, this is an indication that canal preparation is complete. If the file is loose within the canal, F2 can be used and the apical diameter should then be measured using a size 25 K file. It is important that the working length is not altered during the measurement.

If the size 25 K file adjusted to working length fits snugly in the canal, the preparation is completed. If the file sits loosely at the apex, F3 should be used to the working length, and the apical diameter should be measured using a size 30 K file. If the size 30 K file remains loose in the canal, F4 or even an F5 (ProTaper Universal; see p. 170) can be used in the previously described manner to achieve the ideal apical preparation. If some other concepts for apical preparation are preferred by the clinician, the apical size can be measured using hand files following the F1 file and the definitive instrumentation size determined using appropriate clinical concepts.



23.52 ProTaper, step IV

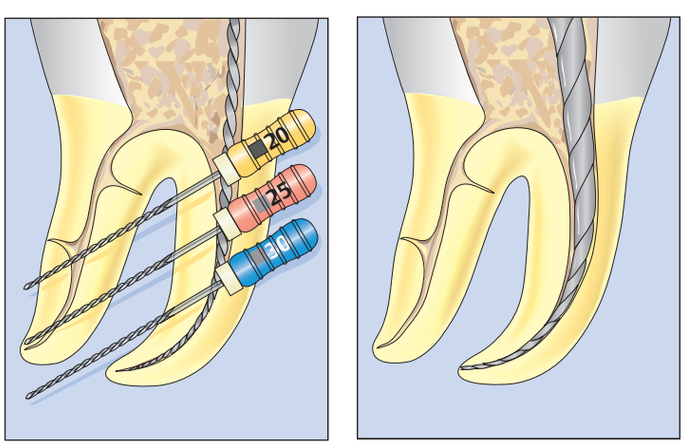
The working length is determined using a size 10 K file. Patency is of great importance and must be kept in mind throughout the entire preparation procedure.
If the canal diameter is narrow, initial apical preparation with hand instruments up to ISO size 20 is necessary to provide a smooth glide path for the rotary instruments.



23.53 ProTaper, step V

Left: S1 is inserted apically with a "brushing" motion.

Right: S1 and S2 are also used with a "brushing" motion to working length. The coronal two-thirds of the root canal system should now be ideally shaped.



23.54 ProTaper, step VI

Left: The apical diameter is measured using a K file to determine the size of the master apical file.

Right: When working with the ProTaper system, it is important to remove the instrument immediately as soon as the working length is achieved to avoid unnecessary transportation of the canal.

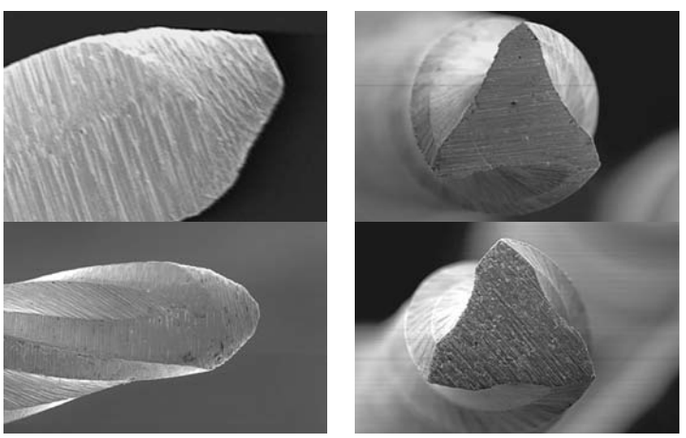
ProTaper Universal

The wide distribution of ProTaper and numerous early studies of torsion, debris elimination, and its fracture characteristics have demonstrated that F2 and F3, when used in curved root canals, cause excessive dentin removal from the inner curvature of the canal, and that the F3 had a tendency to deform and fracture (Calberson et al., 2004). In addition, there has been much discussion about the fact that the largest diameter canal the F3 ProTaper could reach was only 0.30 mm, too small for many root canal instrumentation applications. For this reason the ProTaper Universal was introduced in 2006, with the following characteristics:

- More rounded tips on all finishing files to reduce transportation. The shaping file S2 was given a new form to smoothen the transition from S2 to F1. The F3 has U-shaped grooves to improve flexibility and limit stiffness, and increase the chip space.
- F4 and F5 correspond in transverse section to F3, but have larger tips and different tapers: F4 with size 40 and 6%, F5 with size 50 and 5%, respectively. All ProTaper files are supplied with silicone grips and can therefore also be used by hand.

23.55 ProTaper Universal

In continuation of the initial ProTaper file development program, the design was modified and two additional finishing files (F4 and F5) were introduced. Thereafter the complete ProTaper product was supplied with appropriate paper points, gutta-percha points, and Thermafil obturators.



23.56 SEM images

Left: The ProTaper cutting edges were originally sharp all the way to the tip (top). In the finishing files of the ProTaper Universal set, the file tip is much more rounded to preserve the natural canal shape (bottom).

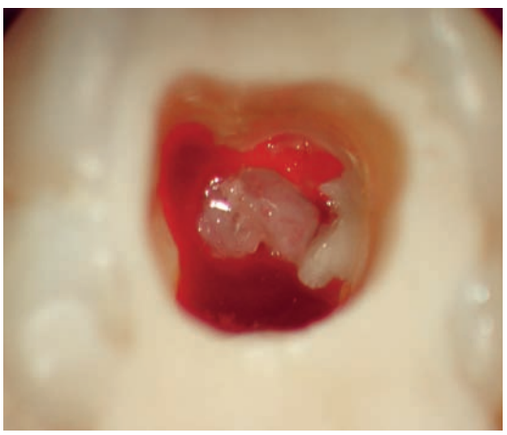
Right: Because the original F3 was very stiff (top), the cross section was changed to a U-shape (bottom). This increased flexibility and led to improved centralization within the canal (courtesy of Dentsply Maillefer).

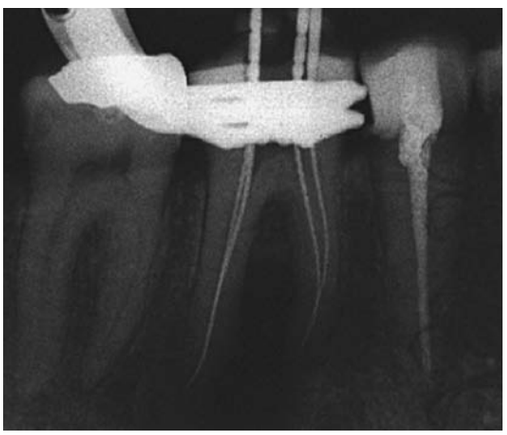
23.57 Initial radiograph

Note the pronounced lesion of endodontic origin around the roots of tooth 46.

- With ProTaper Universal, the concept was expanded to include three files with a very short handpiece shaft of only 11 mm (normal: 15.34 mm) for use in re-treatment:
  - D1: sharp, active tip (size 30) to penetrate into the obturation material, 9% taper;
  - D2: rounded tip (size 25), 8% taper;
  - D3: rounded tip (size 20), 7% taper.
- The recommended working speed is 500–700 rpm for gutta-percha or Thermafil, and 250–300 rpm for zinc oxide eugenol-based obturation material.
- To complete the ProTaper Universal system, paper points, gutta-percha points, and Thermafil obturators in sizes F1–F5 are commercially available.

A study of the causes of fracture of ProTaper instruments in routine clinical use provided some basic information (Spanaki-Voreadi et al., 2006): 17.4% of ProTaper files were only plastically deformed, in 8.7% this led to instrument fracture, whereas 73.9% exhibited no plastic deformation prior to fracture. The conclusion from these clinical observations indicated that a single overloading could lead to a subsequent ductile fracture.





23.58 Treatment progress

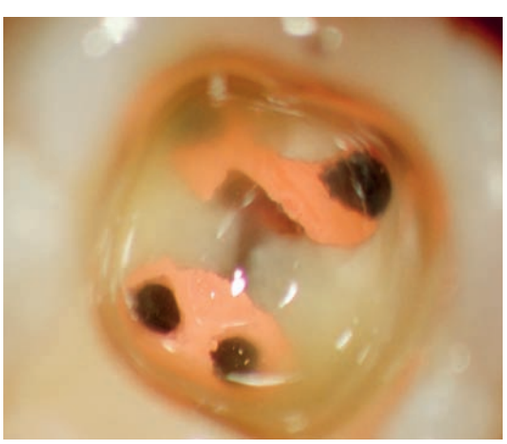
Left: After establishing the primary access cavity, bright red blood has entered the opened pulp cavity. The radicular pulp is highly inflamed.

Right: The radiographic image reveals two confluent mesial canals and also two lumens distally.

23.59 Instrumentation and filling

Left: On the mesial aspect are the usual two, widely separated, mesial canal orifices connected by an isthmus. Distally, a broad lumen is also seen.

Right: The root canals are filled up to the level of the canal orifice. Distally, two Thermafil points have been used to fill the large canal.



23.60 Definitive closure and follow-up

Left: To prevent coronal leakage, the floor of the pulp chamber is etched with phosphoric acid and a dentin bonding agent is applied.

Right: Follow-up radiograph at 1 year postoperatively shows the initiation of reossification of the original extensive periapical lesion, with complete regeneration of the periodontal ligament space.

RaCe And S-Apex

The RaCe files ("reamer with alternating cutting edges"; FKG Dentaire, La Chaux-de-Fonds, Switzerland) have been commercially available since 1999. Even today, their unique feature is the presence of alternate twisted and straight cutting segments, which reduces the screwing effect.

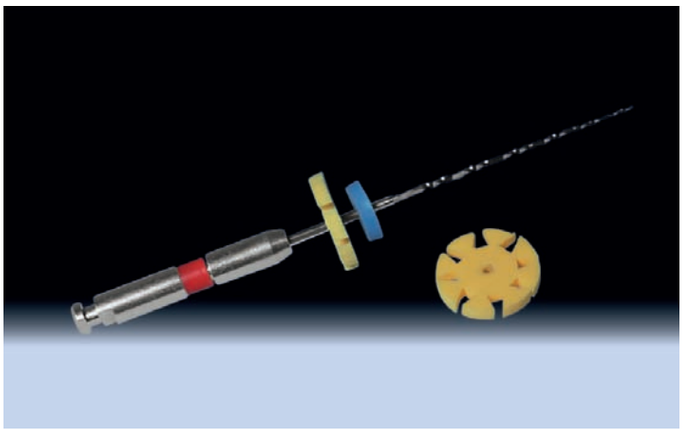
There are, in addition, two stainless-steel instruments with very high taper (40/.10 and 35/.08), and a special coated surface that permits working at speeds of 300–600 rpm. These instruments can be used with both the crown-down and the stepback techniques.

The S-Apex files (FKG) were first introduced in 2004. They exhibit inverse taper (e.g., the tip is thicker than the remaining 16 mm of the cutting edges). This permits the use of rotary instruments at the start of root canal preparation of even very narrow canal systems, and enables the preparation of a defined apical stop both in length and in breadth.

With sizes ranging from 15 to 60, the system provides a broad choice of files for clinical application. The relatively high speed of 500–600 rpm guarantees rapid dentin removal from the root canal. If fracture occurs it is almost always near the shaft, and this permits easier removal.

23.61 RaCe file

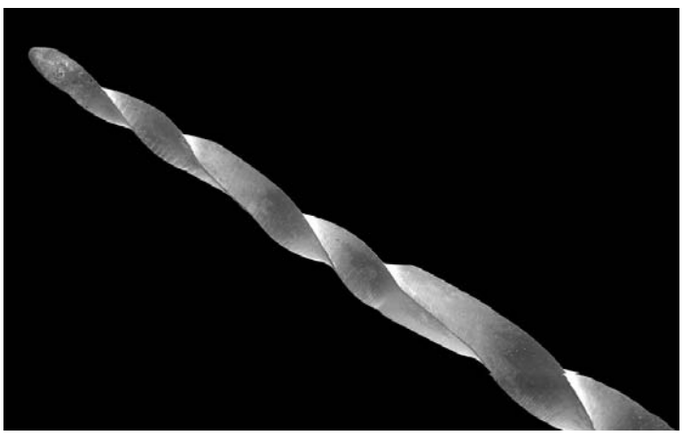
In addition to the usual stop for canal length determination, the RaCe file also has a "floral" stop with eight "petals." Following each use of the file, depending on the clinical situation, one to three of the "petals" should be grasped with a forceps and twisted. This provides clinical control of the use and lifespan of the file.



23.62 SEM image

The SEM image shows the extraordinary geometry of the RaCe file. Note the pattern of straight and then twisted areas along the course of the cutting surfaces from the tip all the way to the handle. This prevents sticking within the root canal, and also provides larger chip spaces.

Right: The S-Apex files have a thicker tip, resulting in an actual inverse taper.

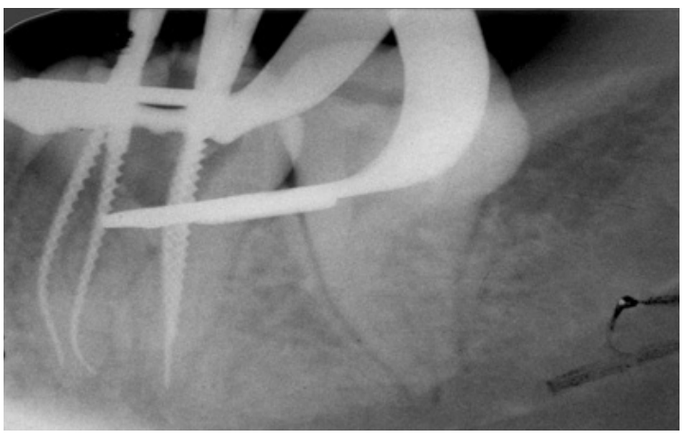


23.63 Initial radiograph

Tooth 36 had been opened. The patient complained of persisting pain, which led to endodontic referral. The diagnostic radiograph reveals an extensive restoration extending into the pulpal cavity and evidence of calcium hydroxide dressings at the root canal orifices. The lumen of the canal and the mesial root are clearly diminished as revealed by the radiograph.

Over 40 research studies have illuminated many aspects of these file systems. On extracted teeth, RaCe instrumentation provided relatively good cleaning and maintained the original curvature significantly better than ProTaper (Schäfer and Vlassis, 2004). In another study, both systems were highly rated for respecting the original curvature of the root canal and being safe to use (Paqué et al., 2005). In comparison to other well-known systems such as FlexMaster, GT, ProFile, and ProTaper, RaCe was rated as safe and more effective (Schirrmeister et al., 2006b).

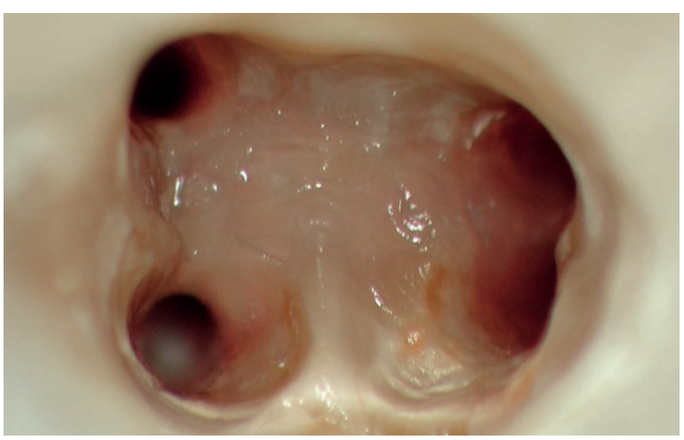
In an SEM study of all areas of the root canal, the cleaning effect and shaping with RaCe was clearly better than with hand instrumentation (Baumann et al., 2003). The removal of a previously placed gutta-percha filling was faster with RaCe and ProTaper than with Hedström (H) files or FlexMaster files (Schirrmeister, 2006c). Vertically condensed Epiphany with its companion sealer was easier to remove with H files as well as with RaCe, better than gutta-percha with AH Plus (Schirrmeister, 2006a).



23.64 Master point radiograph

Left: Following detection and exposure as well as initial widening of the four canals, a radiograph was taken to determine canal length.

Right: The radiograph shows two completely separately coursing mesial canals and two additional canals distally, which are confluent in the apical region.



23.65 Completion of the instrumentation

Following root canal instrumentation the clinical view shows the two mesial canals connected by an isthmus, as well as two distal canals close together whose lumens are communicating over a broad area.

23.66 Root canal filling

The follow-up radiograph shows a homogeneous root canal filling up to the root apex as well as minor extrusion of sealer at the root apex.

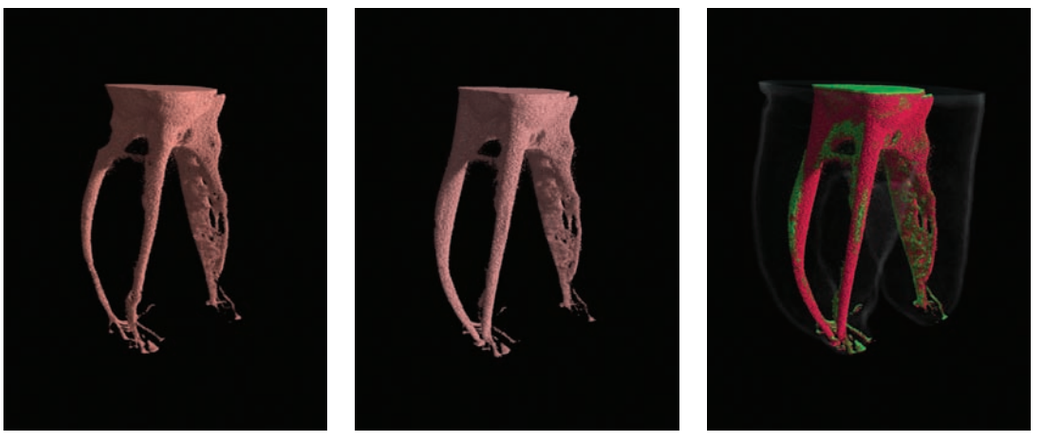
Left: The clinical view shows the Thermafil pins, which have been cleanly severed at the canal orifices.

Summary and Conclusions

In vitro experiments

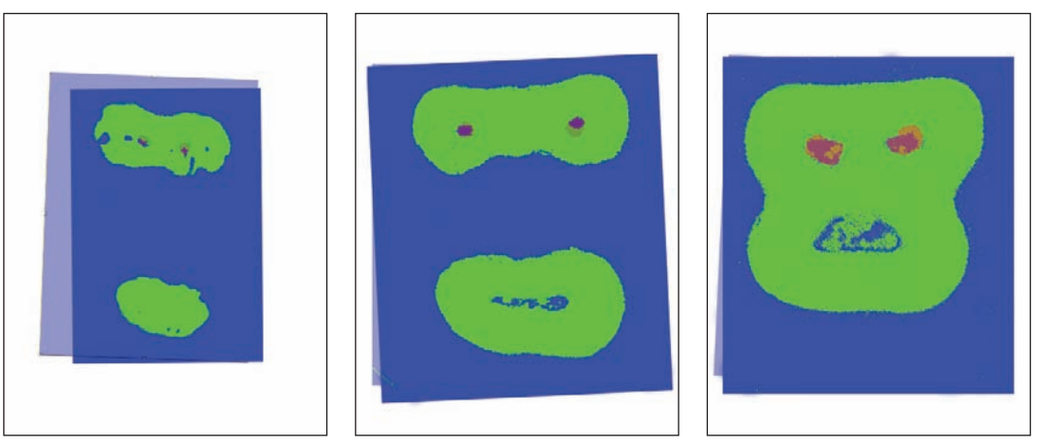
In laboratory studies, different root canal instruments have been subjected to varying procedures designed to test the behavior of those instruments in root canal models or extracted teeth. Highly informative results have been obtained through an analysis of high-resolution computed tomography data sets. In these studies, teeth were scanned before canal instrumentation and three-dimensional data were used to create reconstructed images. Following instrumentation, the test procedure was repeated and the before and after canal models were superimposed. Canal shape changes were then able to be evaluated mathematically.

The results of most interest included, primarily, alteration of the root canal axis, as well as changes in the internal surface of the root canal. The experiments included evaluation of instrumentation errors, such as hourglass-shaped canal form (zipping and elbowing) and perforations on virtual root canal models or horizontal sections. The same canal models can be superimposed and the prepared canal surfaces examined using appropriate color coding. With adequate spatial resolution (<40 μm) it is possible to objectively compare root canal preparation techniques and instruments.



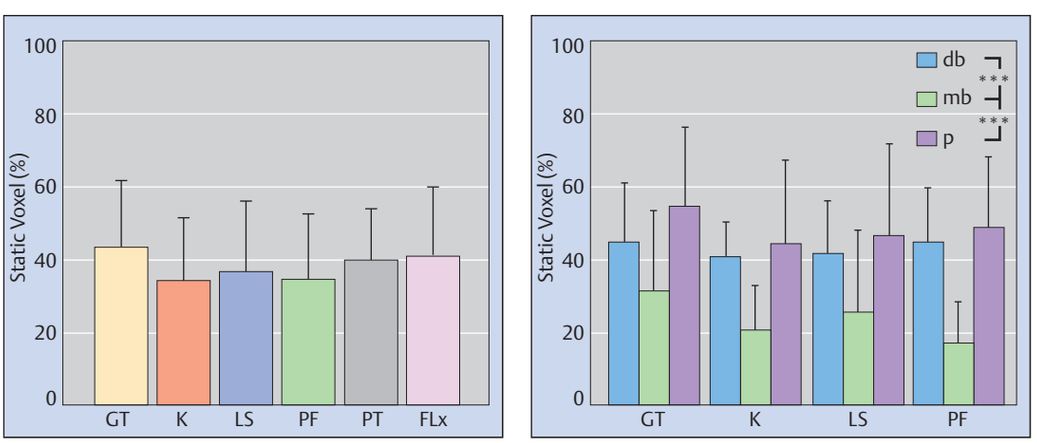
23.67 3D root canal models

Root canals before preparation (left) and following preparation (middle), as well as the superimposition of both data sets (right). The external contour of the root is shown as transparent. Noninstrumented sections of the root canals appear as a result of the summation effect as red (following preparation) and green (before preparation), while fully instrumented sections of the canal appear as red. The clearly green colored areas represent dentin debris-filled areas that persisted even after canal preparation.



23.68 Canal cross sections

Horizontal sections of root canals based on high-resolution computed tomography (same experiment as in Fig. 23.67). The illustrations demonstrate data from the coronal, middle, and apical thirds of the roots with superimposition of horizontal root canal sections before and after instrumentation. Orange sections represent the anatomic situation following instrumentation, while those in red represent superimpositions of pre- and postoperative canal sections.



23.69 Comparative studies of root surface instrumentation

Middle section of a noninstrumented canal surface (± standard deviation) in the entire canal system for NiTi systems GT files, K files, LightSpeed, ProFile, ProTaper, and FlexMaster (left), as well as for distobuccal (db), mesiobuccal (mb), and palatal (p) root canals (right). The data are derived from 45 root canals in maxillary molars.

Clinical Relevance

Not every rotary NiTi instrument is appropriate for every clinician and/or for every type of variation in root canal anatomy. According to the arrangement of the cutting edges, currently available instruments are classified into three groups:

- instruments with passive cutting behavior (radial lands, Group I);
- actively cutting instruments (Group II);
- special cases such as LightSpeed or the Liberator (Group III).

In vitro investigations have demonstrated that with regard to maintenance of the natural root canal access, as well as in relation to instrumentation errors, no instrument or instrument set is superior to any other set.

For the novice clinician, instruments with built-in security measures (fracture characteristics, instrumentation errors) may be more suitable. For an experienced clinician, on the other hand, the new generation of more active cutting instruments may be more attractive because they reduce clinical working time and enable the creation of desired canal shapes.

The shape and design of the instrument determines other effects such as the amount and quality of the smear layer produced. The cross-sectional design of the instrument as well as the arrangement of cutting surfaces along the instrument shaft influence fracture resistance. The determining parameters, however, are always the clinician and the proper and appropriate use of the instrument.

Even without definitive proof of better clinical results, one can state today with certainty that the use of NiTi rotary instruments significantly improves root canal instrumentation. Clinical studies by Pettiette et al. (1999, 2001), Peters et al. (2004), and Cheung and Liu 2009 provide evidence in this direction.

All endodontic instruments today have a noncutting tip, an important criterion for maintaining the natural root canal access and therefore clinical safety. Newer power-driven systems offering torque limitation provide the inexperienced clinician with an easy introduction to the clinical technique, but cannot completely prevent instrument fracture.

The greatest potential problem with NiTi instruments is the feared, occasional instrument fracture. However, recent comprehensive follow-up studies (Spili et al., 2005) did not document any serious problems related to instrument fragments left within the canal, if all other phases of the clinical procedure were executed optimally.

Single-use (disposable, "throw away") NiTi instruments present one way to eliminate problems such as fracture or corrosion following repeated use, and may also provide improved clinical results.

	Instrument	Possible instrumentation	Instrumentation errors	Fractures	Clinical results
I	ProFile GT Quantec Pow-R Guidance	• + • Dependent on size • Time-consuming	• ++ • Seldom, usually below 150 µm	• +/− Fatigue • + Torsion • Dependent upon system	• ++ • Dependent on preoperative diagnosis • To date, no difference between instruments, except for beginners
II	K3 RaCe Hero ProTaper Mtwo	• +/− • Use of hybrid technique possible	• +/− • Seldom, but technique intensive	• + Fatigue • +/− Torsion • Dependent on taper and shape	
III	Special cases	• Varies • + LightSpeed	• +++ LightSpeed • −− Other systems	• Varies	• Varies

23.70 Categorization of instruments

Classification of currently available NiTi instruments based on their cutting efficiency and in vitro criteria.

23.71 Clinical cases

Endodontic procedures carried out in the same patient on maxillary molars using stainless-steel instruments (left) and rotary NiTi instruments (right). The preparation error (apical perforation) is clearly discernible (left).
The error did not occur with use of power-driven rotary instruments for the preparation (right).

24 The Hybrid Concept of Nickel-titanium Rotary Instrumentation

For any given root canal, use of a specific instrument X or a certain technique Y will not necessarily be successful. This is because the various endodontic systems on the market have quite different characteristics that may or may not deliver as expected in a given situation depending on the root canal configuration. Within these facts is embedded the idea of the *hybrid* concept: Depending on the individual root canal anatomy and the associated, special difficulties, the root canal preparation must be carried out with a logical and reasonable instrument sequence, which ideally has been selected for the individual clinical situation.

The hybrid concept has previously been published in parts (Walsch, 2004). The illustrations within this chapter provide examples in increasing levels of difficulty, as well as a description of the hybrid sequence used in each case.

The ultimate clinical goal is a predictable treatment outcome with ideal preparation and without procedural errors. In this regard, various types of instrument of varying sizes and various techniques are used together in order to combine their advantages and to eliminate as many disadvantages as possible. This demands knowledge about the cutting characteristics of the various instruments (where does it cut and how does it cut within the course of the root canal).

To understand a hybrid sequence, the clinician must be aware of the most important characteristics of the various instrument systems (see Instruments and Materials: Design of Nickel-titanium Files, p. 80). In this chapter we will describe the most important basic rules regarding the use of Nickel-titanium (NiTi) rotary instruments, and the three fundamental concepts of root canal instrumentation.

Nickel-titanium Rotary Instrumentation Rules

In order to enhance the safety of all NiTi rotary instrumentation techniques, several rules must be observed:

- The slowest recommended speed appears to be the safest (Gabel et al., 1999; Dietz et al., 2000).
- Always lubricate NiTi rotary instruments (RC-Prep, Premier Dental, PA, USA).
- Ensure there is support for the clinician's hand (to compensate for patient movement and for better control of the instrument, and also to reduce the "screwing in" effect).
- Ensure continuous irrigation/flooding of the root canals with sodium hypochlorite (or EDTA) during root canal preparation.
- Minimize apically directed pressure on the instrument.
- Permit the instrument to continuously rotate (from introduction into the canal until removal).
- Minimize the cutting time (immediately withdraw the instrument on reaching the desired length).
- Each new introduction of the same instrument should penetrate more deeply into the canal.
- Following the removal of each instrument it should be cleaned and inspected, and replaced as necessary/appropriate.
- Following the use of each instrument, the canal must be thoroughly irrigated, recapitulated, and re-irrigated.
- Apical patency must be regulary confirmed/checked.

These rules are more critical for actively cutting instruments than for passive ones. Use of active as opposed to passive instruments leads more readily to procedural errors, especially in inexperienced hands. Before clinical use, every new instrument system must be tested by practicing on extracted teeth. It has been shown that the frequency of fracture and deformation of instruments is reduced with increased clinical experience (Baumann and Roth, 1999).

Crown-down Technique

A series of instruments of decreasing size or taper are used in the crown-down technique; each file reaches deeper into the canal. In this way, the next smaller or less-tapered instrument cuts deeper apically than the previous one. The repetition of such a sequence results in deeper access within the canal and/or further enlargement of the canal diameter.

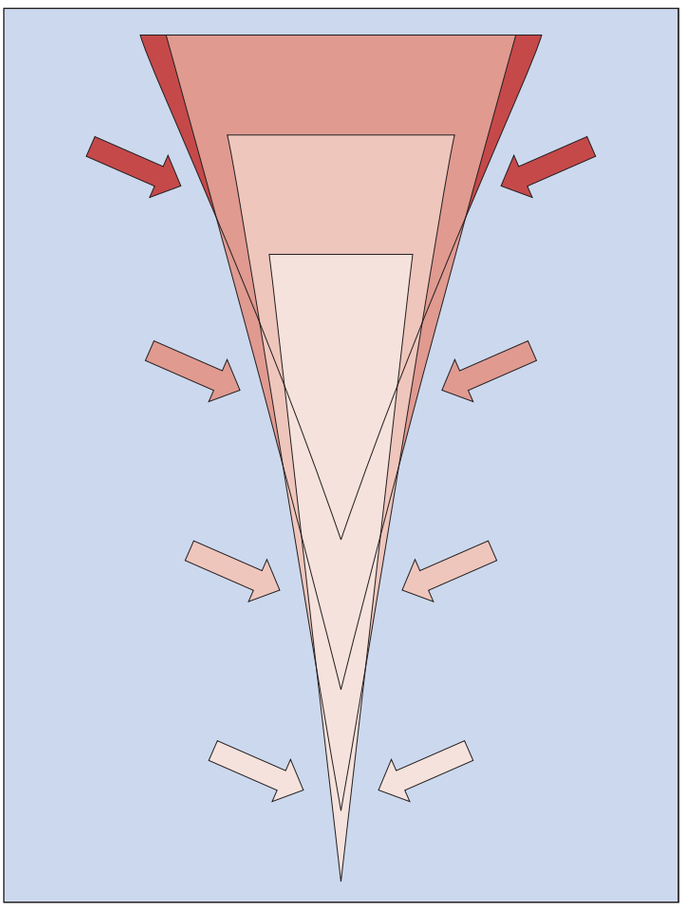
The particular problem of taper lock occurs if within the crown-down sequence only the instrument size is varied while maintaining the same taper. For this reason, the latter should also be varied more often. The variable taper of ProTaper instruments helps avoids this risk.

The crown-down technique minimizes coronal interference, simplifies instrument penetration, increases apical tactile sensitivity, reduces canal curvature, minimizes working length changes during preparation, and allows penetration of irrigating solutions down to the full depth of the preparation, which reduces bacterial accumulation before apical instrumentation.

Thus the crown-down technique minimizes iatrogenic apical contamination, reduces the area of contact between the instrument and the canal wall, so reducing torque, increases cutting efficiency and safety, and reduces the frequency of procedural error.

24.1 Crown-down technique

Use of the crown-down instrumentation sequence with decreasing taper produces a “flare form” (upside-down Eiffel Tower) within the canal with more coronal taper and less apical taper. This is illustrated by the overlapping of the variously tapered instruments in the figure. The arrows indicate those sections of the canal wall where the corresponding instruments actually cut.



24.2 Straight-line access, radiographic views

Left: The arrows indicate the direction of insertion of the root canal instruments before any straightening.

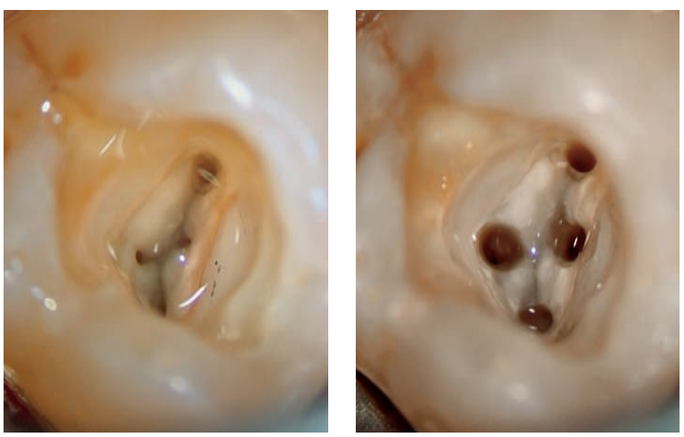
Right: Orifice widening in the outlined areas leads to removal of dentin overhangs in the outer aspect of the curvature without risking a perforation or excessively compromising tooth structure; the result is a straightening of the path of insertion (arrows) with a significant reduction of the angle of the canal curvature.

Stepback Technique

In this technique, a series of instruments of increasing sizes are used with the first instrument reaching furthest apically; each subsequent instrument is inserted less deeply than the previous instrument. Thus, each instrument creates a small step coronal to the depth reached by the previous (smaller) instrument. This creates a "pseudo-tapered" root canal, whose taper is determined by the size difference between any two instruments and the distance between their respective penetration depths. If, instead of selecting an instrument of bigger size, increased taper size is selected, the result will be a flare form, similar to that shown in Fig. 24.1.

A comparison between the crown-down and the stepback techniques revealed that the crown-down technique is associated with less contact of the instrument tip with the canal wall as well as lower force application and torque load on the instrument. The conclusion is that the crown-down technique is safer than the stepback method (Blum et al., 1999).

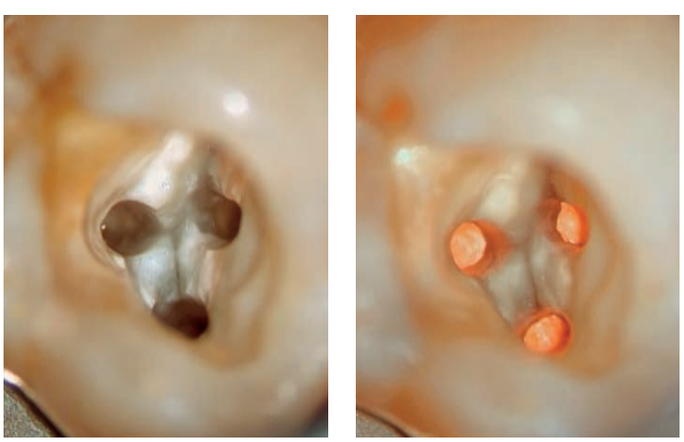
The *single-length* technique involves the use of a series of instruments with increasing size or increasing taper, with all instruments used to the same length or even to the estimated working length. This technique is important for the final stages of apical preparation.



24.3 Straight-line access, initial

Left: Access cavity before straight-line access preparation.

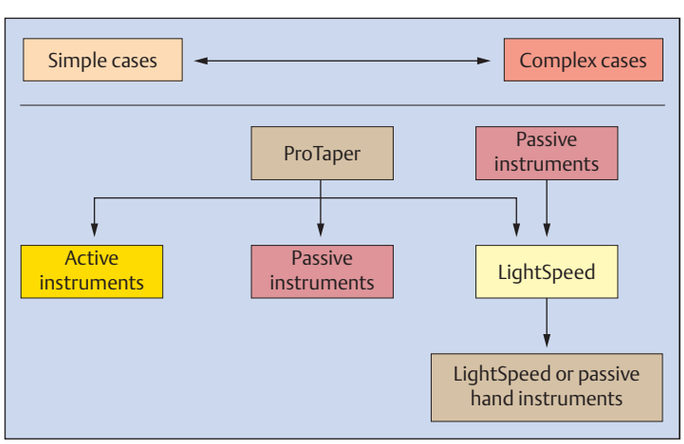
Right: Access cavity flooded with irrigating solution following preparation of straight-line access into the root canals and preparation of the coronal third of the root canal using Gates-Glidden drills.



24.4 Straight-line access, final

Left: Buccal canals following complete instrumentation.

Right: Buccal canals after root canal filling.



24.5 Overview of the hybrid concept

Left, simple cases; right, complex cases. Body shaping and apical preenlargement: Usually ProTaper, but in complex cases usually passive instruments.

Apical enlargement: Depending on difficulty, active or passive and LightSpeed instruments with stepback as necessary for determination of the master apical file (MAF) size.

Apical finish: With LightSpeed MAF size or another passive instrument, which can easily and passively be inserted to the working length.

Extent of Root Canal Preparation

The ideal preparation shape is summarized in Schilder's definition (1974): "A three-dimensional, continuously tapering cone in multiple planes [with sufficient apical enlargement] preserving foramen position and size."

Prerequisites: Ideal access cavity, straight-line access to the root canals, radicular access with Gates-Glidden drills or orifice-shaping instruments (see Chapter 17), and a glide path to file size 15, using the hand instrumentation technique "watch winding and pull" for small instruments and the balanced-force technique (Roane et al., 1985) for larger instruments.

With regard to the size of the apical preparation, the literature states that:

- The optimal enlargement of each canal should be calculated based on the size of the initial file that binds at the apical portion of the canal (Weine, 1996); the apex should be enlarged at least three file sizes greater than its original diameter (Grossman, 1974).
- Because of their special shape, LightSpeed Classic instruments are more suitable than K files for estimating the original apical diameter (Levin, 1999; Wu, 2002); in general, measurement values tend to be too small, therefore underestimating the original canal diameter (Levin, 1999; Wu, 2002).
- In addition, root canals are usually *not* round apically (Green, 1958; Wu, 2000), and only the smallest canal diameter can be measured. Anatomic investigations have demonstrated that the apical canal diameter in many cases corresponds to an instrument size 30–40, or even larger (Kuttler, 1955; Kerekes and Tronstad, 1977a, b, c). During canal enlargement, published "average" values (Ingle and Taintor, 1985; Kasahara, 1988) cannot always be adhered to (Kasahara, 1991). In each individual case, clinical observation is necessary to define the MAF ("master apical file") size, and all available information concerning root canal anatomy and the potential technical difficulty of the case must be included in the final determination.
- A final *round* cross section of the apical preparation would be ideal, because this would provide improved cleaning of the canal wall and a better apical seal during the root canal filling (Luks, 1965; Hwang, 1998). This is often impossible, however, particularly with ribbon-shaped canals; nevertheless the clinician should strive to achieve the goal of a rounded apical preparation as closely as possible, and this usually means instrumenting to a larger size than originally planned. Based on these points the decision is made up to which size the instrumentation should be performed.

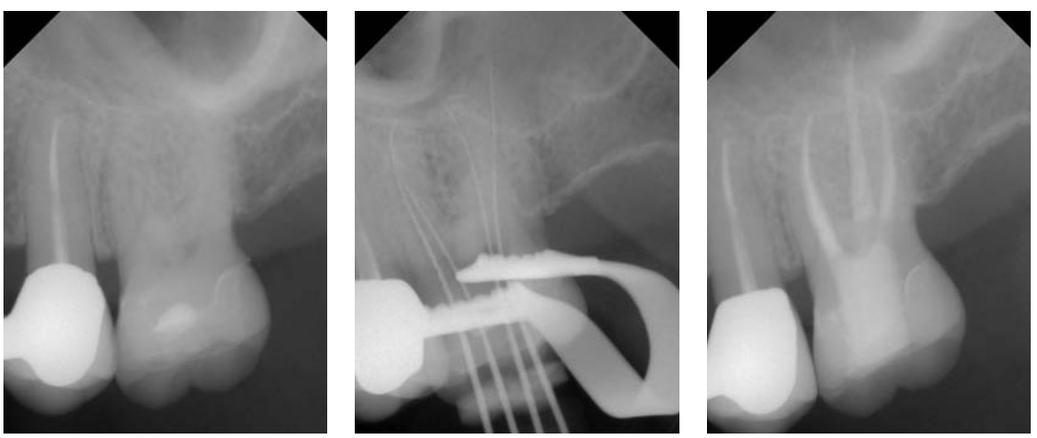
24.6 Clinical case I

Mild root canal curvature. Straight-line and radicular access: Gates-Glidden drills, sizes 1–3, 4–1. Body shaping and apical pre-enlargement: ProTaper up to F3.
Apical enlargement: FlexMaster 35/.04, 35/.06, 40/.04, 40/.06. Taper lock was avoided. Active instruments chosen due to low degree of difficulty.

Left: Preoperative radiograph.

Middle: Radiograph for working length determination.

Right: Postoperative radiograph (orthoradial projection).

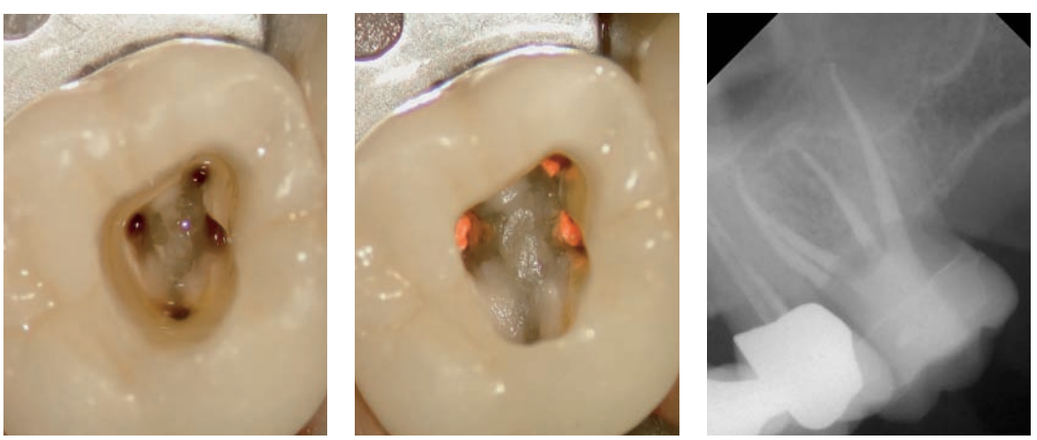


24.7 Clinical case I

Left: Access cavity.

Middle: Access cavity following root canal filling; mb1, mb2, and db are visible.

Right: Postoperative radiograph, distal eccentric projection. The mb canal configuration is Vertucci type II.



Shaping the Body of the Root Canal

The first step is to quickly and effectively remove material from the coronal and middle thirds of the canal. The classic GT file set has proven to be ideal for this procedure, and is used with decreasing taper in the crown-down technique. The sequence can be repeated as necessary until the working length has been reached.

The end result should be a flare form with an apical diameter of at least size 20. Active instruments such as ProTaper SX, S1, and S2 are even more effective for this procedure. Use of these instruments results in a flare form with the highest amount of taper in the coronal portion of the root canal.

Subsequently, the taper is increased deeper and deeper into the root canal: The taper "wanders" from the coronal into the middle third of the canal. This can also be considered a crown-down procedure in that the taper is reduced in a crown-down manner. The resulting canal shape permits ideal access for the apical preparation.

24.8 Clinical case II

Slight curvature with a distal apical bend.
Straight-line and radicular access: Gates-Glidden 4–1. Body shaping and apical pre-enlargement: ProTaper up to F3, distally to above bend, F2 to full working length. Apical enlargement: ProFile mesially 35/.04, 35/.06, 40/.04, 40/.06, 45/.04; distally 35/.04, 35/.06, 40/.04, 40/.06, 45/.04, 45/.06, 50/.04, 55/.04 up to bend 30/.02, 30/.04, 35/.02 to full working length. Mesial isthmus was opened using ultrasonic and Hedström (H) files manually.

Right: Orthoradial postoperative radiograph.

24.9 Clinical case II

Left: Access cavity with opened mesial isthmus.

Right: Access cavity following root canal filling.

24.10 Clinical case II

Left: Mesial eccentric postoperative radiograph.

Right: Distal eccentric postoperative radiograph.

Apical Preparation

There are four steps, all of which may not be necessary in each individual case:

- Apical pre-enlargement.
- Apical enlargement.
- Apical LightSpeed preparation.
- Apical finish.

Apical Pre-enlargement

The apical third of the canal can be quickly and effectively enlarged to a size that can be reached safely. In simpler cases, this can be carried out with aggressive, active instruments such as ProTaper, RaCe, etc.

ProTaper F1–F3 will provide an ideal apical preparation shape, provided that F3 reaches the working length. This instrument sequence will move the taper even further apically (crown-down).

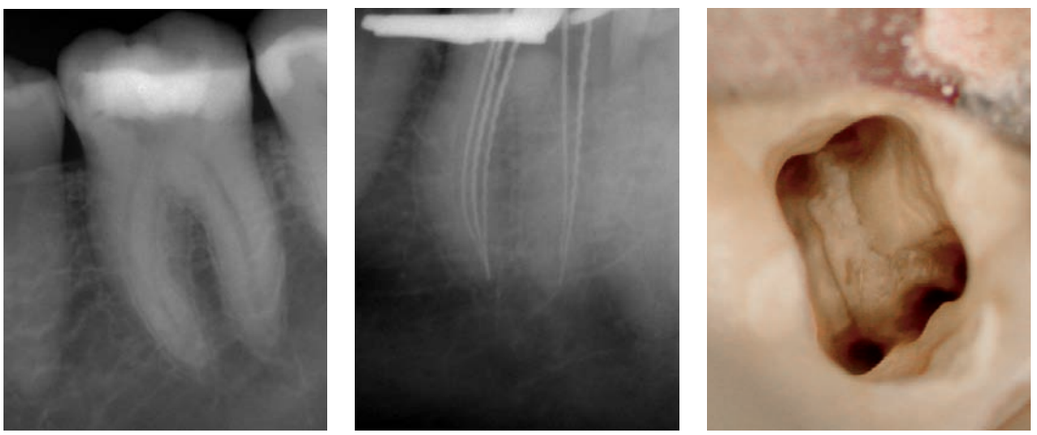
ProTaper can play an important role in the hybrid concept: Use of a complete sequence of these instruments can provide both body shaping and pre-enlargement with ease.

24.11 Clinical case III

Moderate, coronally located curvature with an S component mb. Gates-Glidden drills 1–3, 4–1. ProTaper up to F3, mesially by hand. M central and ml confluence during instrumentation. Apical enlargement: ProFile in alternating tapers up to 35/.06 or 40/.04 in all canals, as well as distal using LightSpeed to size 60 and step-back to size 100. Apical finish: ProFile 60/.04 in a clockwise motion, by hand. Distal isthmus opened using ultrasound and H files by hand.

Middle: Working length radiograph.

Right: Access cavity before obturation.

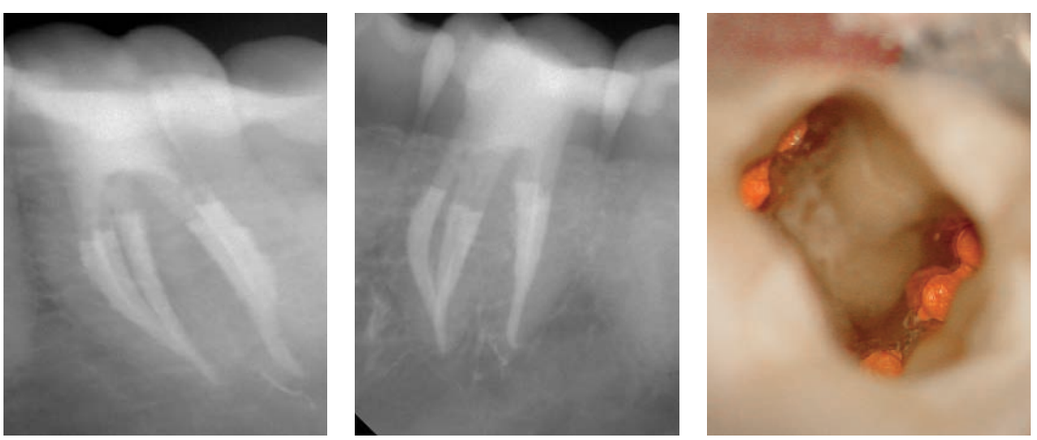


24.12 Clinical case III

Left: Postoperative radiograph, mesially eccentric projection.

Middle: Postoperative radiograph, distal eccentric projection.

Right: Access cavity following root canal filling.



Apical Enlargement

If a larger MAF appears to be necessary, an apical enlargement of 2–3 mm is usually sufficient. Either active or passive tapered instruments can be used. Increasing difficulty of the case (canal curvature, curvature radius, extensive coronal curvature) may dictate the use of passive and/or flexible instruments. In very difficult cases, NiTi instruments can be used manually.

Figure 24.13 presents a comparison of file diameters of the variably tapered instrument ProTaper F3 (multitapered) and other constant tapered NiTi instruments with tapers of .06, .04, and .02 and sizes 35–50 at a distance of 0–5 mm from the instrument tip. Areas in which instruments with constant taper are larger than ProTaper F3 are indicated with an asterisk (Fig. 24.13).

With file size 35, for example, following instrumentation with ProTaper F3 to a predetermined length, the subsequent use to the same length of an instrument with constant taper and size 35 cuts only at the tip: in cases of .02 and .04 taper at less than 1 mm distance and with .06 taper less than 2 mm because the size of a ProTaper F3 1 mm from the tip corresponds to a size 39 (0.39 mm) and 2 mm from the tip to a size 48.

An instrument of size 50 with a .04 taper applied after using ProTaper F3 cuts 4 mm apically; with a .02 taper it only cuts 2 mm.

The basis for this comparison becomes obvious: After reaching the working length with ProTaper F3 it is not difficult to enlarge the final apical portion of the canal. Following use of the ProTaper F3, other active NiTi rotary instruments can be used (e.g., FlexMaster) or passive ones (e.g., ProFile) in sizes of 40 and taper of .06 or .04, and even in sizes up to 50 with a .02 taper, with minimal coronal interference, minimal contact and cutting surface, and therefore minimal torque load. If in a clinical case the desired MAF size was 50 with a taper of .04, following the use of ProTaper F3 apical enlargement of approximately 4 mm would be required.

To reduce the torque load for each subsequent instrument, the following instrument sequence could be applied: 35/.04, 35/.06, 40/.04, 40/.06, 45/.02, 45/.04, 50/.02, and 50/.04. In the majority of cases, all instruments in this sequence can reach the working length without excessive resistance (single-length concept).

Parts of the instrument sequence described can be repeated until the working length is achieved (step-down). The number of individual instruments may appear to be quite large, but each instrument has only a minimal cutting job to do, which is achieved after only one to three rotations. At this point, the instruments can be used by hand, which will be quicker than changing files in the handpiece, as well as safer, with less intracanal transportation.

The more severe the canal curvature, the smaller the taper selected for apical preparation should be and the more often passive and/or flexible instruments should be used. At a distance of several millimeters from the working length the difference between the existing ProTaper F3 preparation form and the size of the instrument used for apical widening is so large that the instrument assumes a straighter configuration within the canal curvature and does not need to be as severely bent in order to follow the course of the root canal. In some cases, the same instrument would not have been able to follow the same kind of curvature without previously carrying out the above-described apical pre-enlargement.

	Distance to tip (mm)	Diameter (mm) of ProTaper F3 (taper in %)	Diameter (mm) of constant tapered NiTi instruments					
			6% taper		4% taper		2% taper	
Size 35	0	0.30 (9%)	0.35*		0.35*		0.35*	
	1	0.39 (9%)	0.41*		0.39		0.37	
	2	0.48 (9%)	0.47		0.43		0.39	
	3	0.57 (9%)	0.53		0.47		0.41	
	4	0.64 (7%)	0.59		0.51		0.43	
	5	0.71 (7%)	0.65		0.55		0.45	
Size 40	0	0.30 (9%)	0.40*		0.40*		0.40*	
	1	0.39 (9%)	0.46*		0.44*		0.42*	
	2	0.48 (9%)	0.52*		0.48		0.44	
	3	0.57 (9%)	0.58*		0.52		0.46	
	4	0.64 (7%)	0.64		0.56		0.48	
	5	0.71 (7%)	0.70		0.60		0.50	
Size 45	0	0.30 (9%)	0.45*		0.45*		0.45*	
	1	0.39 (9%)	0.51*		0.49*		0.47*	
	2	0.48 (9%)	0.57*		0.53*		0.49*	
	3	0.57 (9%)	0.63*		0.57		0.51	
	4	0.64 (7%)	0.69*		0.61		0.53	
	5	0.71 (7%)	0.75*		0.65		0.55	
Size 50	0	0.30 (9%)	0.50*		0.50*		0.50*	
	1	0.39 (9%)	0.56*		0.54*		0.52*	
	2	0.48 (9%)	0.62*		0.58*		0.54*	
	3	0.57 (9%)	0.68*		0.62*		0.56	
	4	0.64 (7%)	0.74*		0.66*		0.58	
	5	0.71 (7%)	0.80*		0.70		0.60	

24.13 Size comparisons

Comparison of the file diameter of ProTaper F3 files with variable tapers and other NiTi rotary instruments with constant tapers of .06 (6%), .04 (4%) and .02 (2%) in sizes 35, 40, 45 and 50 at a distance of 0–5 mm from the instrument tip. All values are given in millimeters.
Areas in which instruments with constant tapers larger than ProTaper F3 are found are indicated by an asterisk.

Apical LightSpeed Preparation

This step is necessary whenever the desired MAF or apical taper cannot be achieved with tapered NiTi rotary instruments in a curved canal (Hülsmann, 2002), since they are too stiff beyond size 60. To date, LightSpeed files can prepare the apical portion of a severely curved canal to the widest degree with the least deviation (Knowles et al., 1996; Thomson and Dummer, 1997).

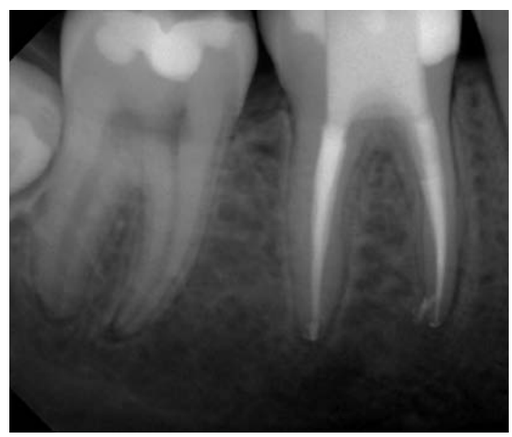
Continuing on from the previously achieved size, the apical portion of the root canal is now widened with LightSpeed in increasing steps, beginning with the next size beyond the previously achieved apical size. All instruments should be used to the estimated working length, and no instrument in the sequence should be omitted.

Because the apical preparation shape now achieved is cylindrical, a stepback procedure must be carried out with LightSpeed instruments to achieve apical taper. Steps of .05 mm with LightSpeed files of up to size 60, 1 mm for sizes 60 and 70, and 2 mm for 70–100 will provide a "pseudo-taper" of .05. The resulting steps on the side of the greater (outer) curvature can inhibit or limit penetration of an irrigation needle or a gutta-percha point, especially with sizes beyond 60.

24.14 Clinical case IV

Apical curvature with a narrow radius. Straight-line and radicular access: Gates-Glidden drill 4–1. Body shaping and apical pre-enlargement: ProTaper up to F3, distal and mb to full working length, mesial and ml up to F2 by hand, and only up to point of confluence with mb canal. Apical enlargement distally with ProFile instruments, alternating taper up to 45/.06, mesio-buccal up to 40/.06, mesial/mesiolingual up to 35/.04; subsequent use of ProTaper F3 by hand. Distal isthmus opened with ultrasound, H files by hand.

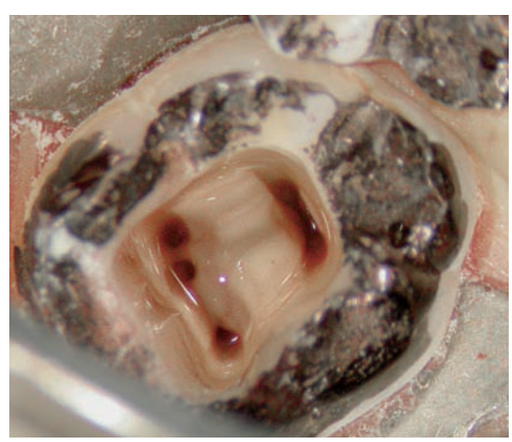
Right: Postoperative radiograph, orthoradial projection.



24.15 Clinical case IV

Left: Postoperative radiograph, mesial eccentric projection.

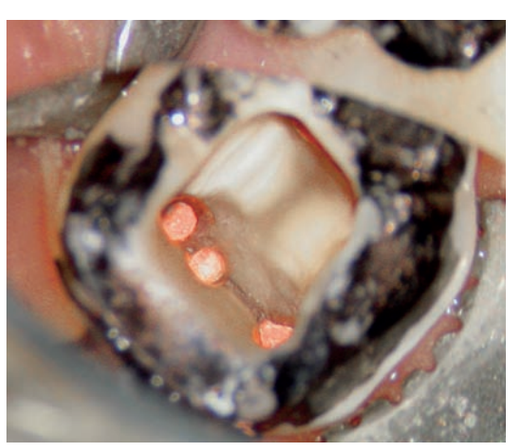
Right: Access cavity.

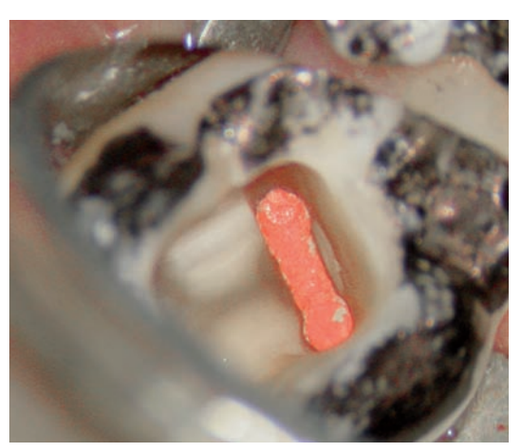


24.16 Clinical case IV

Left: Access cavity following root canal filling, mesial aspect.

Right: Distal aspect.

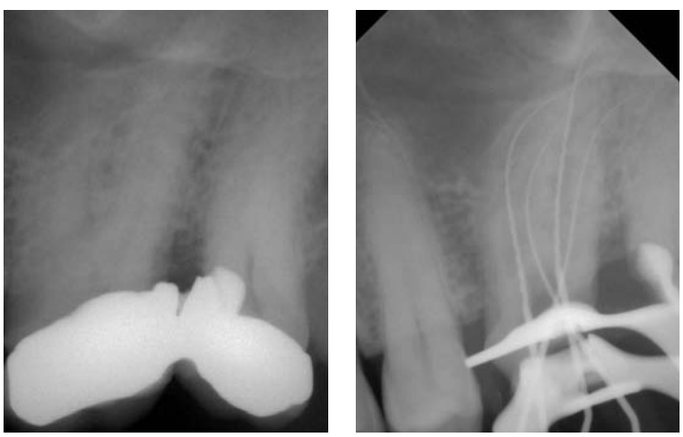




Apical Finish

The previously mentioned steps created on the outer aspect of the curve of the canal can be reduced by apical finishing: The LightSpeed MAF or another passive instrument with a small taper and a size that can easily and passively be moved to the working length can be used in a rotary motion, or wound clockwise one or two times by hand to the working length.

In this way, the steps are smoothened and the stepback (pseudo) taper regains continuity with the coronal crown-down taper preparation. The entire hybrid concept can be condensed to the overview shown on page 179, and newly developed instruments can be included easily into this concept.

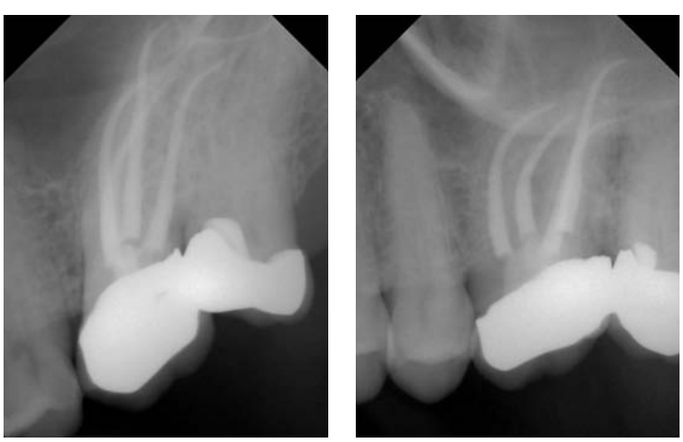


24.17 Clinical case V

Working length 25.5 mm, severe curvature up to 90°, and a moderate radius of curvature. Straight-line and radicular access: Gates-Glidden drills 1–3, 4–1. Body shaping: ProTaper in several sequences (crown-down), with the final sequence at the working length for apical pre-enlargement using ProTaper up to F3 by hand. Apical enlargement: ProFile, buccal 35/.04 and 40/.04, palatal up to 60/.04.

Left: Preoperative radiograph.

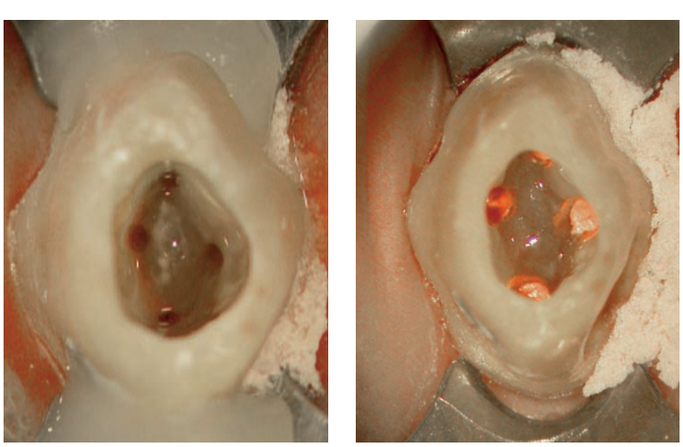
Right: Radiograph for working length determination.



24.18 Clinical case V

Left: Postoperative radiograph, orthoradial projection.

Right: Postoperative radiograph, distal eccentric projection, showing mb canal configuration of Vertucci type IV.



24.19 Clinical case V

Left: Access cavity.

Right: Access cavity following root canal filling.

Limitations of the Hybrid Concept

- Severe curvatures in the coronal part of the root canal, especially with long canal lengths apical to the curvature, cannot be instrumented using tapered NiTi rotary instruments. LightSpeed or NiTi hand files are indicated in such cases.
- Curvatures of extremely small radii (<2 mm) should not be instrumented using power-driven instruments. Use of NiTi K hand instruments with a .02 taper with the modified balanced-force technique (Roane et al., 1985), and manual use of LightSpeed, pre-bent K-FlexoFiles, or similar instruments is recommended.
- In S-shaped curvatures, power-driven file systems should only be used up to the point where the curvature changes its direction; beyond that level, only hand instruments should be used.
- Ribbon-shaped canals are best treated using the "circumferential filing" technique. NiTi rotary systems may be deflected in such circumstances by canal unevenness or narrowing, or may become stuck and pulled in a different lateral direction within the canal, with ensuing danger of instrument fracture.
- C-shaped canal structures should in general be instrumented by hand due to the unpredictable anatomy.
- Apically bifurcated canals often cannot be instrumented using straight instruments. Pre-bent steel or NiTi instruments can be used under microscopic control in tip-limited filing movements. Pre-bent NiTi rotary instruments should *never* be rotated!
- Confluence of root canals, which is quite common in the mesial roots of mandibular molars, often occurs not at the apex but rather further coronally. One of the root canals often runs directly from the pulp chamber orifice to the apex without any extreme curvature or bend (main canal), whereas the other canal (accessory canal) may join the main canal at an extreme angle.

Following the course of the accessory canal all the way to the apex would mean forcing the instrument around a sharp bend (or a severe curvature with an extremely small radius). In the early stages of root canal preparation, the clinician should attempt to identify the main canal and localize the point of confluence with the accessory canal using small hand files and tactile sense. The next step would be to prepare the main canal to the working length. Only then should the accessory canal be instrumented to its point of confluence with the main canal. Finally, the main canal should be recapitulated and irrigated to get rid of residual debris.

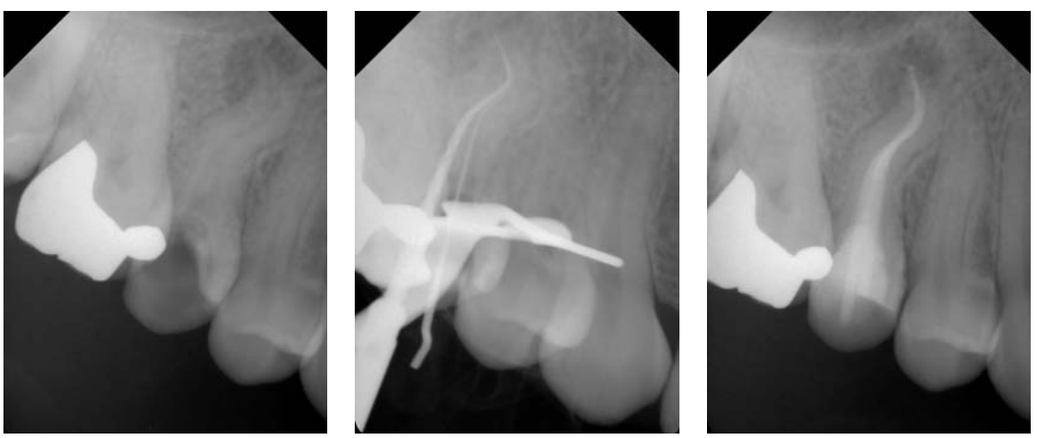
24.20 Clinical case VI

S-shaped curvature.
Straight-line access: Gates-Glidden drills 4–1. Radicular access and body shaping: ProTaper, sequentially and by hand, with F1 to the full working length. Apical pre-enlargement: RaCe up to 25/.04.
Apical enlargement: LightSpeed up to size 35, stepback up to 50 in 1-mm increments. Apical finish using LightSpeed size 35 file.

Left: Preoperative radiograph.

Middle: Working length radiograph.

Right: Postoperative radiograph.

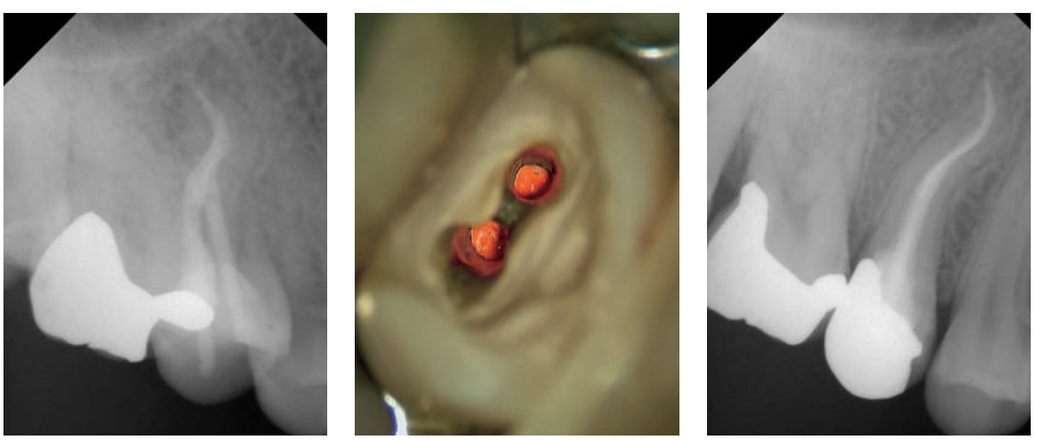


24.21 Clinical case VI

Left: Postoperative radiograph, mesial eccentric projection.

Middle: Access cavity following root canal filling.

Right: Follow-up radiograph after 12 months.



25
Root Canal Disinfection

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Disinfection

Disinfection of the root canal system using solutions and substances with antibacterial and tissue-dissolving properties — the so-called "chemical debridement" — is a critical component of root canal preparation and instrumentation. This procedure is therefore often also referred to as "chemo-mechanical" preparation. Adequate disinfection is critical for successful completion of any endodontic therapy.

In cases of pulpal necrosis, in which there is bacterially induced tissue destruction, 10^6–10^8 microorganisms per milliliter of canal content have been observed; these are primarily anaerobic organisms. In cases of endodontic failure, mainly Gram-positive, facultative anaerobic bacteria, in particular *Enterococcus faecalis*, and various fungi have been identified (Siqueira and Rôças, 2006).

A proportion of the bacteria occupy the endodontium in the planktonic form; the other portion is incorporated into a biofilm attached to the root canal wall. (A biofilm is a single- or multicellular layer of microbes embedded in an extracellular matrix.) The microorganisms within the biofilm can be quite resistant to the host immune response as well as to antibiotic therapy. Individual microorganisms can be released from the biofilm and maintain the level of infection (Svensäter and Bergenholtz, 2004).

In cases of pulpitis with irreversibly inflamed but still vital and vascularized tissue, which is in transition to necrosis, microorganisms are seldom observed within the root canal system. Irrigation of the canal during instrumentation dissolves and removes both tissue remnants and dentinal debris.

The primary goal of chemo-mechanical preparation of the root canal system is the elimination of intracanal microflora as well as necrotic and/or infected canal contents, and in the case of residual vital pulp the removal of all soft tissues. It has been demonstrated time and again that mechanical root canal instrumentation alone does not eliminate all microflora (Peters, 2004; Haapasalo et al., 2005; Hülsmann et al., 2005). In other words, purely mechanical instrumentation of the root canal cannot sufficiently reduce the bacterial "load" to permit healing and/or prevent apical periodontitis. Additional *chemical* disinfection measures are required, which are included under the umbrella term "root canal irrigation."

Any discussion of, or debate about, particular disinfection strategies is directly dependent on contemporary microbiologic knowledge. Improved methods for the identification of specific microorganisms have recently enhanced our knowledge of the microbiology of an infected root canal system. A direct consequence of this new knowledge is the onus on the profession to seek new strategies for combating the complex microflora. For this reason, it is to be expected that the currently recommended disinfection protocol will (have to) be amended in the near future.

Possibilities and Limitations of Root Canal Disinfection

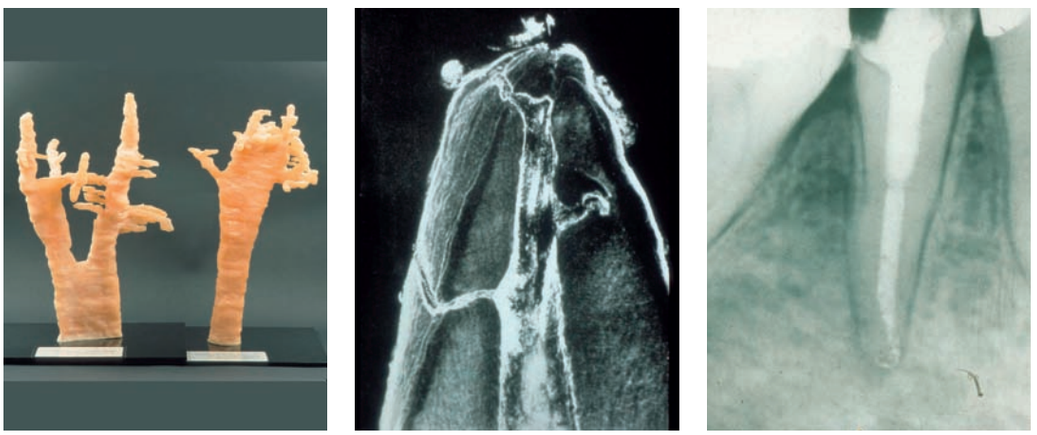
Numerous in vitro studies have demonstrated that a stringent antiseptic treatment protocol will lead to significant reduction of microbiologic contamination of the root canal. Through mechanical instrumentation and saline irrigation alone, the number of microorganisms within the canal can be reduced from approximately 10^6–10^8 microorganisms per milliliter of canal content by a factor of 100–1000 (Bystroem and Sundqvist, 1983). In addition to the removal of necrotic tissue, root canal preparation must also include the introduction of a sufficient volume of irrigating solution into the apical portions of the root canal system. The use of even the thinnest irrigation needle requires preparation to approximately ISO size 35. When sodium hypochlorite is used as an irrigant, approximately 33% of all root canals have been shown to exhibit no residual microorganisms. Increasing the concentration to 5% did not significantly reduce the bacterial count. With the addition of calcium hydroxide the number of bacteria-free root canals increased to 97% (Bystroem et al., 1985). However, consistently reproducible and predictable elimination of microbial contamination has not yet been achieved with any disinfection technique or solution. If a root canal is instrumented and thoroughly irrigated, and then left unfilled but covered with a coronal

25.1 Complexity of the endodontic system

Left: Three-dimensional reconstructions of the root canal systems of a maxillary canine and premolar.

Middle: This histologic specimen clearly demonstrates that some areas of the complex root canal system can only be cleaned chemically and not mechanically.

Right: Following dissolution of soft tissues by means of irrigants, even the areas that could not be instrumented (e.g., lateral canals) were partly successfully obturated.

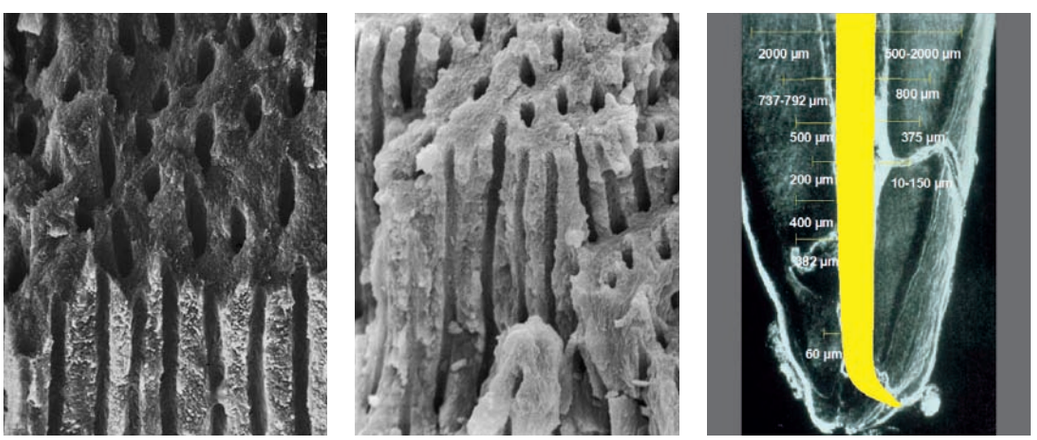


25.2 Dentin structure and infection

Left: From this dentin specimen it is evident that the dentinal tubules are an integral component of the endodontic system, and are clearly susceptible to bacterial colonization.

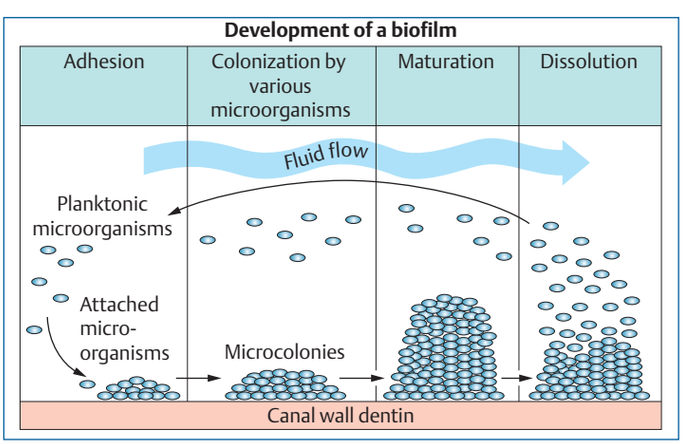
Middle: This dentin specimen clearly shows the large numbers of open lacunae within dentin, all of which are vulnerable to microbial colonization (magnification ×2000).

Right: Depth of dentin infection as shown in numerous research studies.



25.3 Biofilm

The growth of a bacterial biofilm can be divided into various phases: Following attachment of planktonic bacteria onto the canal wall dentin and the formation of an extracellular matrix, a multilayered, 3D biofilm develops. With detachment of microorganisms from the superficial layers, the cycle of biofilm growth is repeated.



filling that aims to provide a bacteria-tight seal, within a week the microorganisms will recolonize to re-establish the initial levels within the root canal.

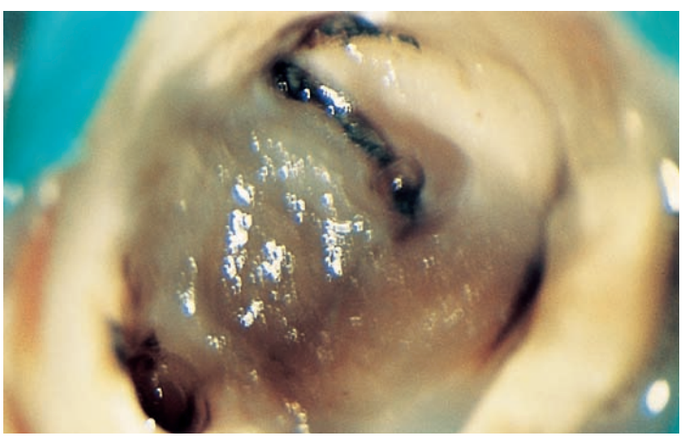
Given the practical impossibility of "sterilizing" the complete root canal system, endodontic treatment is based on the concept of a continuous *reduction* of the bacterial "load" below a pathologically relevant level that can be controlled by the host immune system, as sufficient for endodontic treatment success. A prerequisite, however, is that any reinfection or availability of microbiologic substrate must be prevented by a root canal filling and a coronal restoration, which provide complete sealing.

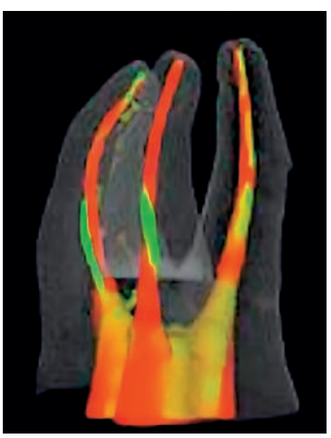
Adequate disinfection of the root canal leading to successful endodontic treatment can only be achieved by a carefully determined series of individual clinical procedures: Application of rubber dam – disinfection of the clinical working field – sterile instruments – adequate size of the access cavities – adequate irrigating solutions, irrigating technique, irrigating time, irrigating depth – antimicrobial intracanal dressing – impermeable root canal obturation – impermeable temporary and definitive restorations, as well as prevention of coronal leakage.

25.4 Clinical effects

The two root canals were not able to be completely instrumented mechanically.

Right: With intensive chemical disinfection, the microbiologic load was sufficiently reduced, leading to complete healing of the periradicular lesion.





25.5 Tissue remnants

Left: After accessing the tooth with a necrotic pulp, magnification ×25 under the clinical microscope revealed tissue remnants within the root canal orifices.

Right: The superimposition of pre- and postoperative structures of the endodontic system clearly reveal that areas of the root canal wall have either not been instrumented or have been only partially instrumented (courtesy of Dr. F. Paqué).

25.6 Failure

Left: The radiograph reveals a homogeneous root canal filling. The periapical tissues radiographically appear free of inflammation.

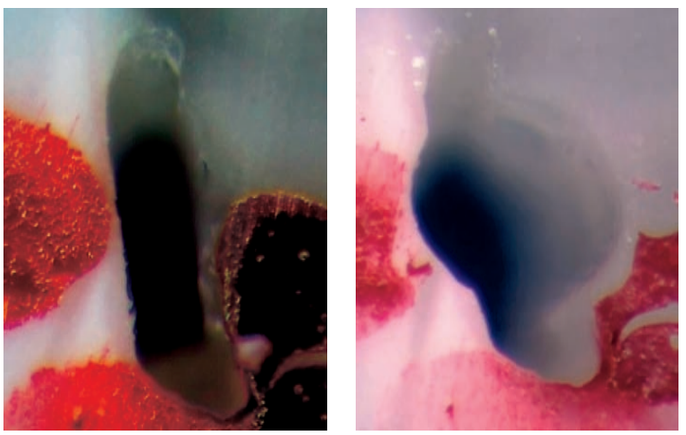
Right: Loss of the definitive restoration led to bacterial recolonization of the root canal and development of apical periodontitis (5 months following root canal obturation).

Disinfection Protocol

Optimum disinfection of the endodontic system will be determined by the initial clinical findings as well as by the suspected extent of microbial contamination. The most important clinical point is to differentiate between infected and noninfected root canals.

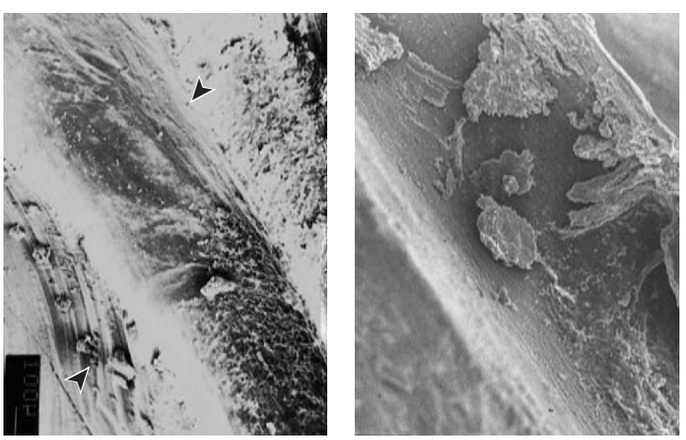
A disinfection protocol for a *noninfected endodontic system* must consider the following clinical observations:

- There are no microorganisms in the deeper levels of the inflamed pulpal tissue. The primary purpose of initial chemical disinfection is to eliminate and remove any soft tissue that was not mechanically removed.
- Irrigation of the root canal assists in removal of dentinal debris created by the instrumentation.
- Irrigation of the root canal should remove any smear layer created by the mechanical instrumentation of the root canal walls.



25.7 Noninstrumented root canal wall region

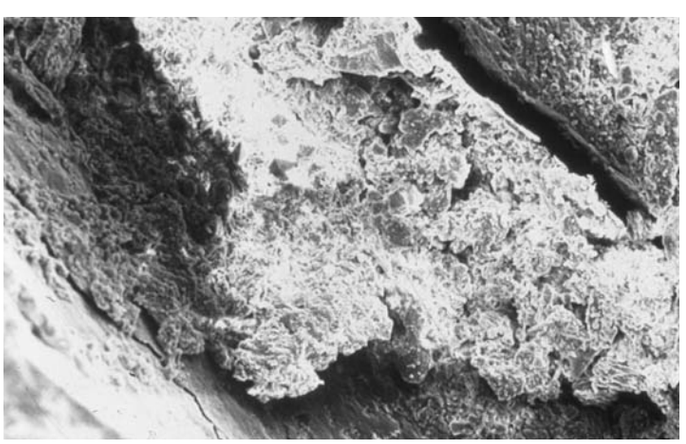
Horizontal sections before and after instrumentation: a smooth and complete preparation of the lateral extensions of the root canal was not achieved.



25.8 Debris

Left: Virtually every canal has noninstrumented sections (arrow), even after intensive root canal preparation.

Right: Following instrumentation there is clear evidence of remaining debris, underneath which a smear layer can be observed (magnification ×200).



25.9 Debris

Massive accumulation of debris following mechanical instrumentation with insufficient removal of dentin and soft tissues.

The disinfection protocol for an *infected endodontic system* must consider the following clinical observations:

- A deep bacterial infection is present in the endodontium, including the dentinal tubules. The precise depth of infection cannot be determined clinically. Mechanical instrumentation of the root canal will only remove a portion of the infected tissues and the infected dentin on the root canal wall. The bacterial "load" can thus be reduced by a factor of 1000–10000 (Bystroem and Sundqvist, 1981).
- The irrigant must be capable of neutralizing bacterial metabolic products (lipopolysaccharides) within the dentin.
- A smear layer will remain following mechanical instrumentation of the root canal walls. The selected irrigant must be effective against the organic as well as the inorganic components of the smear layer.

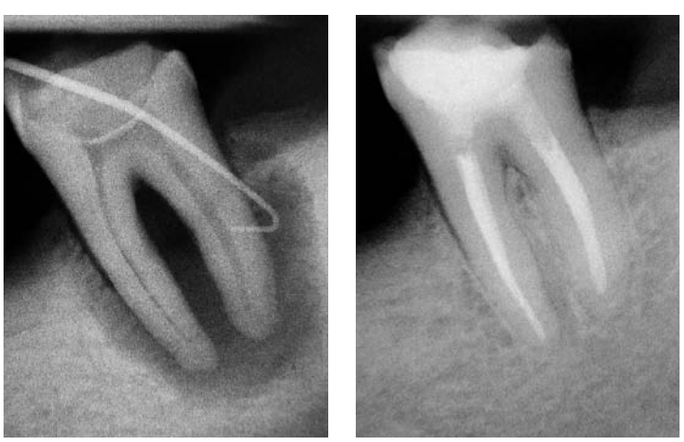
The disinfection protocol for *retreatment* must consider that the bacterial spectrum is most probably different from that of primary endodontic disease and in some cases will consist of microorganisms that are resistant to "traditional" disinfection strategies (e.g., *Candida* species, *Actinomyces*, *E. faecalis*).

25.10 Retreatment

Healing of the periradicular lesion 1 year following disinfection of the endodontic system.

25.11 Retreatment

Removal of the root canal filling material, disinfection, and complete reobturation of the root canal system.



25.12 Apical periodontitis

Complete healing of the lesion within 1 year demonstrating sufficient disinfection of the root canals.

Debris and Smear Layer

Debris is defined as loose accumulations of dentinal chips and remnants of vital or necrotic soft tissues on the root canal wall. Mechanical instrumentation results in the formation of a smear layer on the root canal wall, which can penetrate deeply into the dentinal tubules. The smear layer consists of tissue remnants, cellular debris, dentinal chips, bacteria and bacterial remnants (Koçkapan, 1995; Sen et al., 1995).

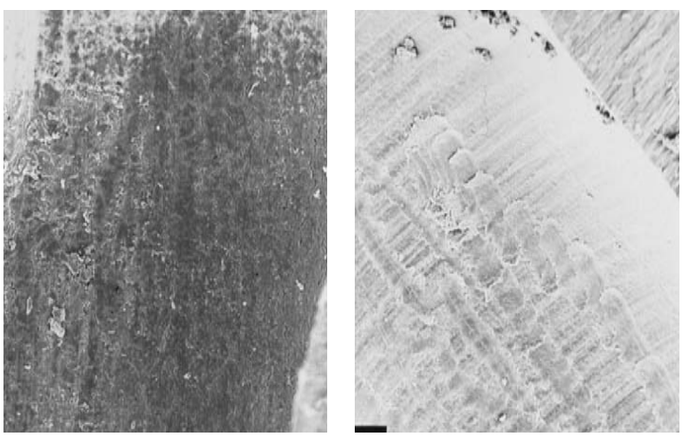
The smear layer not only reduces the permeability of the dentin but also prevents secure adaptation of the root canal filling to the root dentin.

If irrigation of the root canal during the process of mechanical instrumentation is inadequate, a complete blockage of the root canal system can occur, with associated loss of actual working length because of the apical accumulation of dentinal chips and tissue remnants; also, debris from previous coronal restorations can be inadvertently transported towards the apex.

25.13 Smear layer

Left: Following mechanical instrumentation, the root canal wall is covered by a smear layer; no open dentinal tubules are seen (magnification ×1000).

Right: The root canal wall is covered by a smear layer on which additional debris is loosely distributed (magnification ×200).

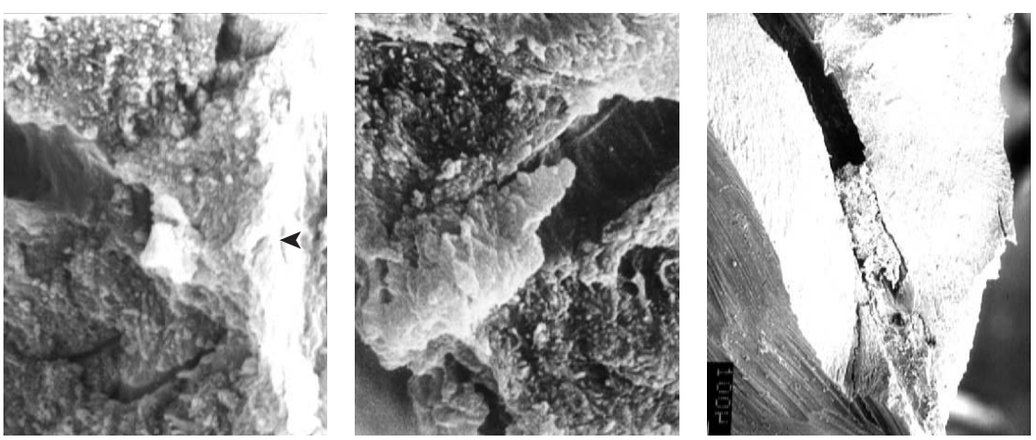


25.14 Smear layer

Left: The smear layer (arrow) appears attached to the root canal wall, and has been forced into the dentinal tubules (magnification ×3000).

Middle: A dentinal tubule clearly blocked by components of the smear layer (magnification ×10 000).

Right: If dentinal debris is not regularly removed by irrigation, the endodontic instrumentation will tend to force such debris apically, leading to irreversible blockage of the root canal (magnification ×100).

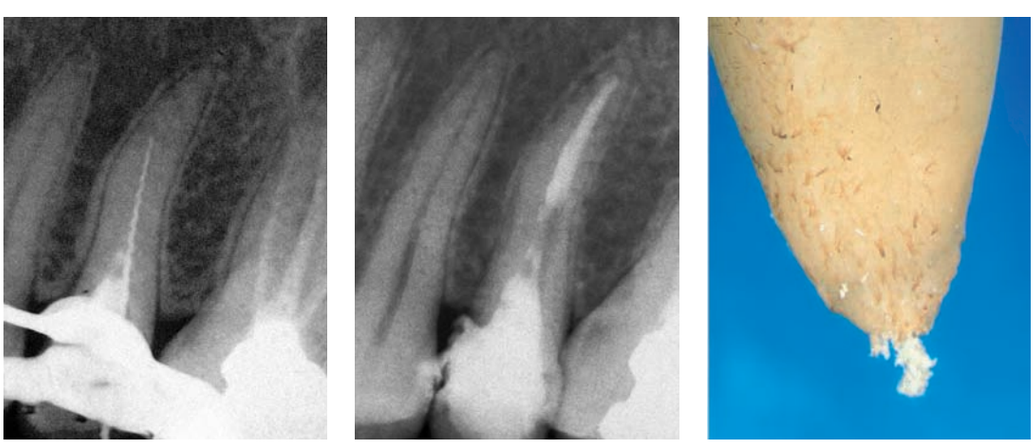


25.15 Apical blockade

Left: Maxillary premolar with a ledge on the outer curvature of the root canal, as well as apical blockade of the root canal. The ledge is probably the result of an attempt to eliminate the blockade by using rigid instruments.

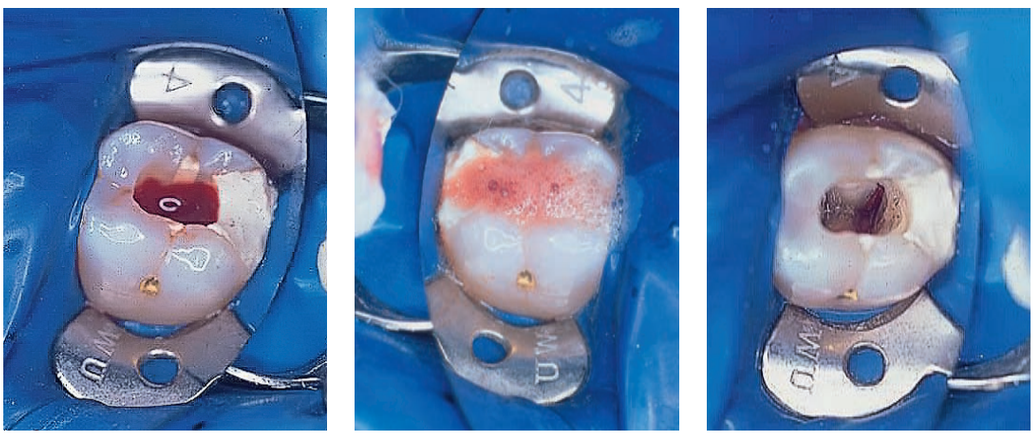
Middle: By means of careful instrumentation and intensive irrigation, it was possible to re-establish the patency of the root canal.

Right: Debris forced through the apical foramen, which can lead to postoperative pain.



The goals of irrigation of the root canal system are as follows:

- Antibacterial action with disinfection of the endodontic system.
- Dissolution and removal of all organic and inorganic canal contents, even from those areas of the complex endodontic system that are not accessible to mechanical instrumentation. This procedure leads to the removal of any substrate on which the remaining bacterial might survive.
- Inactivation of bacterial lipopolysaccharides and dissolution of the biofilm.
- Removal of dentinal chips and debris, therefore preventing any blockade of the root canal, and removal of the smear layer.
- Highest possible tissue compatibility, lowest possible cytotoxicity
- There should be no neutralization of the substances used, no alteration of the characteristics of the hard tissues of the tooth, and no adverse impact on postendodontic restoration (Ørstavik, 2003; Hapasaalo et al., 2005; Hülsmann, 2006).

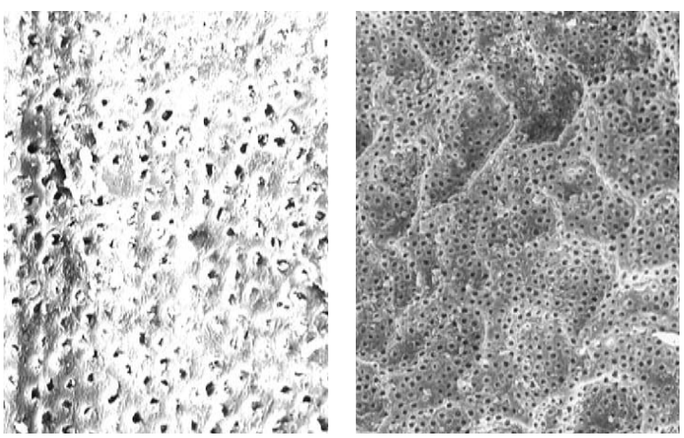


25.16 Sodium hypochlorite (NaOCl)

Left: Profuse pulpal hemorrhage after opening of the coronal pulp chamber in a case of irreversible pulpitis.

Middle: Using a NaOCl-soaked cotton pellet the bleeding has been stopped.

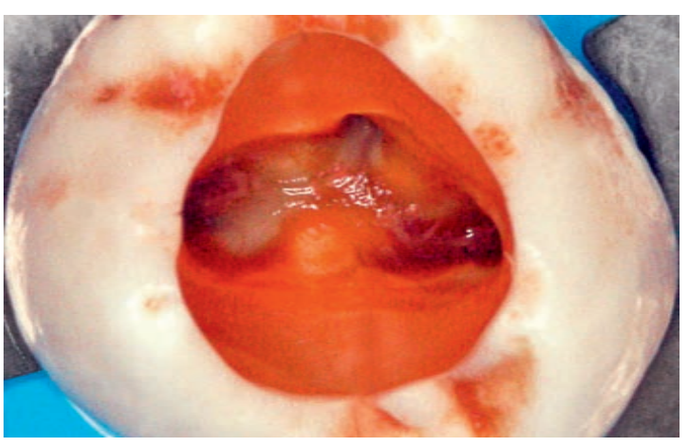
Right: Following cessation of bleeding, a thorough inspection of the pulp cavity is possible.



25.17 Irrigation with sodium hypochlorite

Left: Well-cleaned dentin that is free of soft-tissue remnants (magnification ×250).

Right: Clearly visible root canal wall completely cleared of soft-tissue remnants in a root canal that was not mechanically instrumented (magnification ×500).



25.18 Chlorhexidine digluconate (CHX)

The combination of NaOCl and CHX leads to a brownish discoloration due to formation of parachloraniline.

Irrigants

The most commonly used irrigants are:

- Sodium hypochlorite: This has an effective antimicrobial action against a large variety of endodontically relevant microorganisms. It does not, however, in every case achieve a predictable and/or reproducible elimination of microbiologic infection. With regard to tissue compatibility, concentrations of 1–3% are recommended (Dammaschke, 2003; Ørstavik, 2003).
- Hydrogen peroxide: This dissolves only vital tissue and has less of an antibacterial effect than sodium hypochlorite. No synergistic effect has been demonstrated, so this solution has been eliminated from endodontic irrigation protocols.
- EDTA: Chelators are capable of removing the smear layer and therefore opening the dentinal tubules. Irrigation with EDTA (15–17%) is recommended following instrumentation to enhance the effect of sodium hypochlorite and calcium hydroxide (Heckendorff and Hülsmann, 2002).
- Chlorhexidine: The 2% concentration is recommended for root canal irrigation when problematic microorganisms such as *E. faecalis* are suspected to be present within the root canal (e.g., retreatment procedures). Chlorhexidine does not have any tissue-dissolving properties, and can therefore not replace sodium hypochlorite (Safavi and Spångberg, 2006).

25.19 Chelators

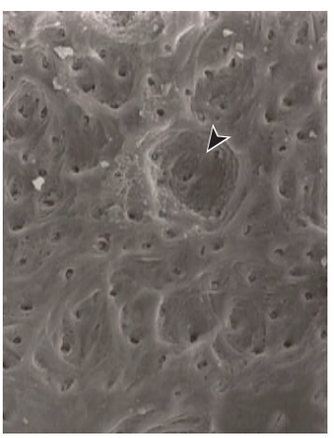
Left: EDTA preparations in the form of a paste are recommended for use during instrumentation.

Right: Dentin surface following application of a chelator paste. The smear layer has been removed and the openings of the dentinal tubules reveal an early stage of demineralization (magnification ×1000).

25.20 Dentinal erosion with use of EDTA

Left: Surface of the root canal wall following irrigation with EDTA. The smear layer has been completely removed and the dentinal tubules are clearly open (magnification ×1000).

Right: With extended exposure to EDTA, erosion of the intracanal dentin can be observed (arrow) (magnification ×1000).



25.21 MTAD

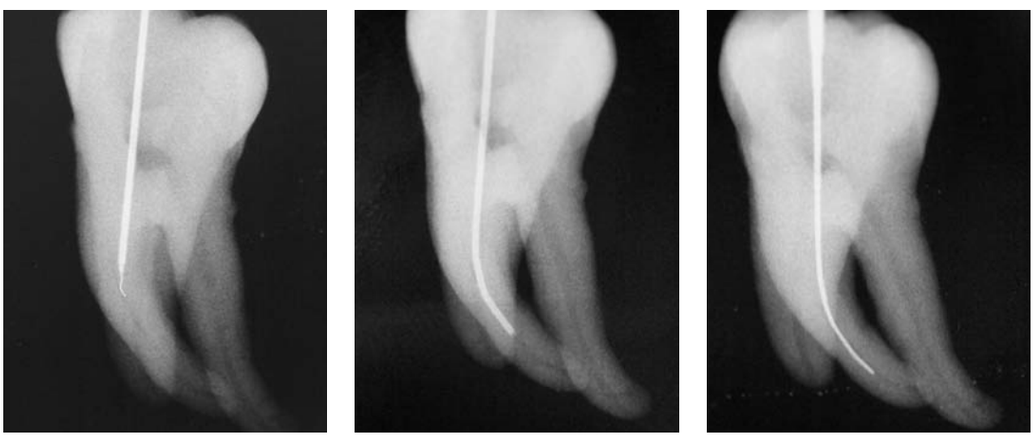
MTAD irrigating solution consists of citric acid, doxycycline, and a detergent, and is recommended for the final irrigation following mechanical instrumentation.

- MTAD (Biopure, Dentsply, Tulsa, OK, USA): MTAD contains an antibiotic, citric acid, and a detergent. A definitive evaluation of this solution is still lacking. Since there is insufficient evidence about the tissue-dissolving capacity of MTAD, it can only be recommended as a supplement to other irrigating solutions (Torabinejad et al., 2003).

Irrigation Technique

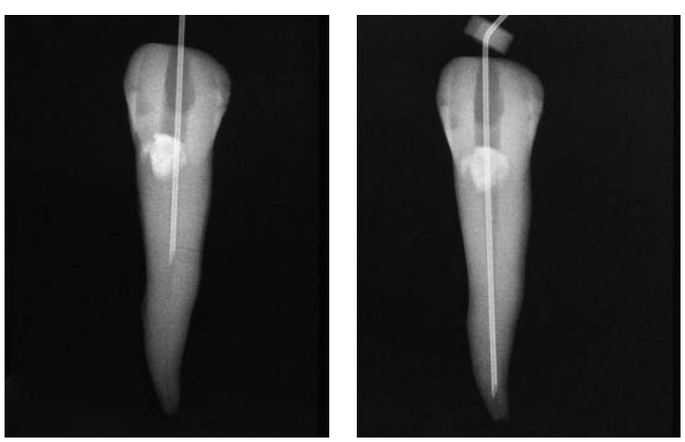
The temperature, the amount of the irrigant used, and the irrigation technique are important factors that influence the efficacy of disinfection. Use of large volumes of the irrigation solution (10–20 mL per root canal) and continuous replacement with fresh solution leads to an improved reduction of bacteria. Heated sodium hypochlorite (45–60°C) dissolves the tissue slightly better and has an improved antibacterial effect, but heating also causes a more rapid decline of the solution's effectiveness.

In addition, it is important to consider the depth of penetration of the irrigation needle (working length minus 2–3 mm, without binding) and the effective contact time of the irrigant with the biofilm (minimum 30 minutes is required) (Kahn et al., 1995; Hülsmann 2006).



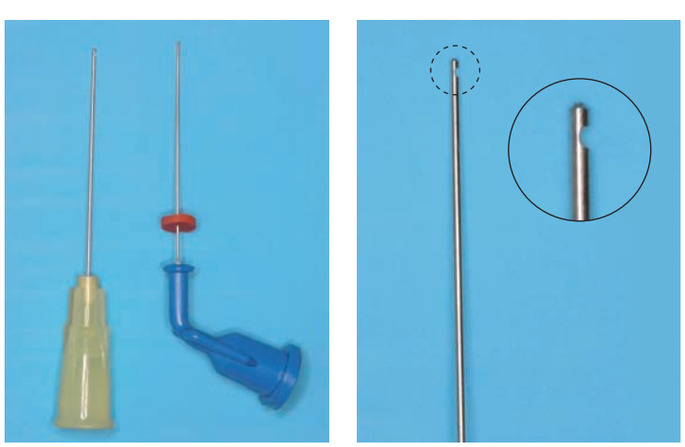
25.22 Irrigation technique

Extremely small-diameter irrigation needles (middle: NaviTip, right: US-needle) can be inserted much deeper than conventional injection needles (left). It is clear from these radiographs that the acute tip prohibits deeper penetration of the injection needle.



25.23 Irrigation technique

As the root canal preparation procedure enlarges the canal, the depth of penetration of the irrigation needle increases with increasing instrument sizes.



25.24 Irrigation technique

Small-diameter irrigation needles.

Left: Maxi-Probe tip (Hawe-Neos, Bioggio, Switzerland) and NaviTip (Ultradent, South Jordan, UT, USA), marked with a rubber stopper to control the insertion depth. The external diameter corresponds to ISO size 30 and ensures deep penetration of the irrigating solution.

Right: The Maxi-Probe needle has a blunt tip and lateral opening.

Ultrasonically Activated Irrigation

With the so-called "passive," ultrasonically activated irrigation system (Van der Sluis, 2006), a file is oscillated at high frequency (approximately 25–30 kHz). This creates vibrations in the irrigating solution (1–3% sodium hypochlorite), warms it, and increases its antibacterial efficiency.

A series of microbiologic investigations on reduction of bacterial load (Sjögren and Sundqvist, 1987; Spoleti et al., 2003) and scanning electron microscopic studies of the instrumented root canal walls (Stamos et al., 1987; Cheung and Stock, 1992; Hülsmann et al., 1997; Sabins et al., 2003) have demonstrated a clear superiority of sonic or ultrasonically activated irrigation in comparison with conventional manual irrigation techniques.

The antibacterial effect of ultrasonically activated irrigation can be attributed to the following factors (Van der Sluis, 2006):

- removal of planktonic bacteria by purely mechanical effect;
- killing of bacteria;
- destruction of the biofilm.

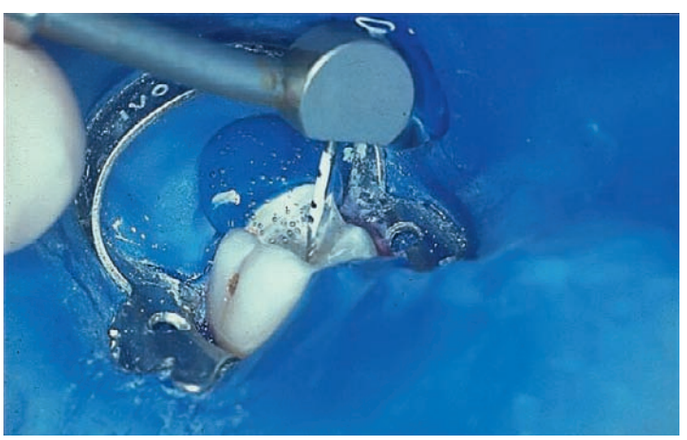
25.25 Ultrasonic device

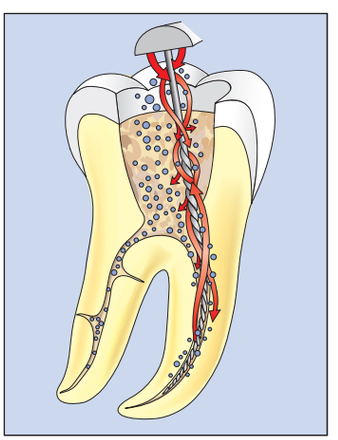
Ultrasonic devices with interchangeable irrigant containers. Most of these devices are also used for periodontal therapy.

25.26 Ultrasonic oscillations

The ultrasonically activated files transfer the oscillations to the fluid.

Right: Mechanism of ultrasonic oscillation.

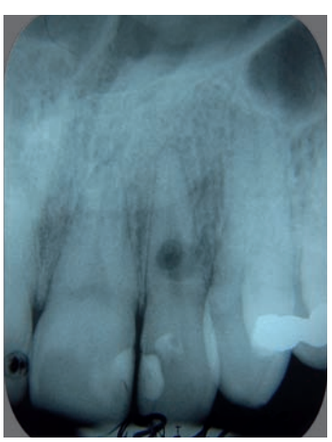


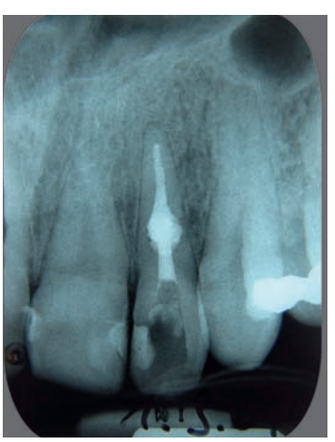


25.27 Effect of ultrasonic irrigation

Left: Preoperative radiograph of a tooth with internal root resorption.

Right: Follow-up radiograph following ultrasonic irrigation and root canal filling with thermoplastic gutta-percha and mineral trioxide aggregate (MTA).

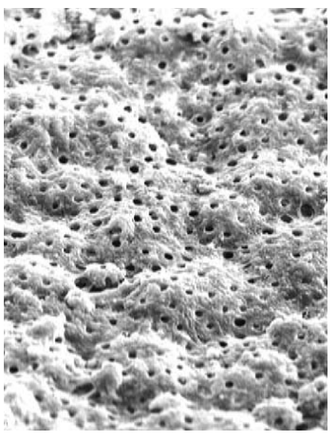




Ultrasonically activated irrigation has proven to be extremely effective, especially in narrow root canals (ISO sizes 20–25), (Kahn et al., 1995) and its success can be attributed to the initial deep penetration of thin ultrasonic needles and the positive effects of the acoustic streaming phenomenon as well as the high volume of fluid flow. These positive effects also extend beyond those areas of the root canal system that cannot be physically instrumented (lateral canals, isthmus, internal resorption lacunae, lateral accessory canals or oval or slit-shaped root canals, etc.)

In order to avoid ledge formation on the root canal wall, dentin removal, and any damping of the ultrasonic oscillations, a passive sonic or ultrasonic irrigation procedure is recommended, i.e., the ultrasonic file should oscillate freely within the irrigant without any contact to the root canal walls (Jensen et al., 1999; Sabins et al., 2003; Spoleti et al., 2003; Van der Sluis, 2006). For this reason, in curved root canals it may be necessary to prebend the instrument to achieve effective cleansing without ledge formation (Ahmad et al., 1992; Lumley and Walmsley, 1992).

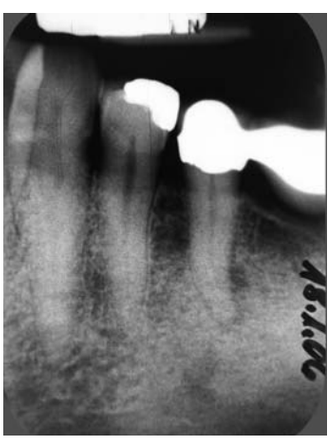
The irrigation time should be 20–30 seconds for each root canal.



25.28 Effect of ultrasonic irrigation

Left: Root canal wall following ultrasonic irrigation with water as the irrigant. The root canal wall appears clean, with open dentinal tubules (magnification ×1000).

Right: Noninstrumented area of the root canal wall. Following ultrasonic irrigation, all tissue remnants have been removed (magnification ×1000).



25.29 Effect of ultrasonic irrigation

By means of intensive ultrasonic irrigation with 1% sodium hypochlorite, it was possible to achieve healing of the lateral inflammatory lesion by adequately reducing the number of microorganisms.

25.30 Effect of ultrasonic irrigation

Left: Note the grooves in the root canal wall following active use of ultrasonic files (magnification ×250).

Right: Grooves in root canal dentin following ultrasonic irrigation (magnification ×250).

New Irrigation and Disinfection Systems

In the past few years, attempts have been made to increase the effectiveness of root canal disinfection using innovative application systems. Included in this have been attempts to treat the root canal system with hydrodynamic techniques (RinsEndo) (Braun et al., 2005; Muselmani et al., 2005, 2006), vacuum pumps (noninstrumentation technique [NIT] as proposed by Lussi [Lussi et al., 1995]), use of brushes, alternating current (Endox), ozone, or laser energy.

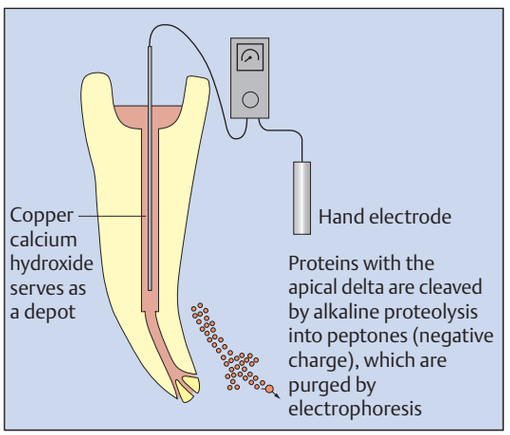
For most of the relatively new systems and techniques it is not yet possible to reach definitive conclusions or make recommendations because the effectiveness and safety aspects have not yet been sufficiently tested, and because some systems are not yet commercially available.

- RinsEndo: This relatively new application system is designed to clean the endodontic system using hydrodynamically activated sodium hypochlorite. To date, this new system has not proved superior to ultrasonically activated techniques, but has demonstrated a higher risk of apical extrusion of the irrigant (Hauser et al., 2006).
- Endox: This device uses high-frequency alternating current to vaporize the soft tissues within the root canal system.

25.31 Depot-phoresis

Left: The depot-phoresis device has two electrodes that conduct the current through the tooth.

Right: Schematic illustration of the operating mode of the depot phoresis device, based on data from the manufacturer.



25.32 Depot-phoresis

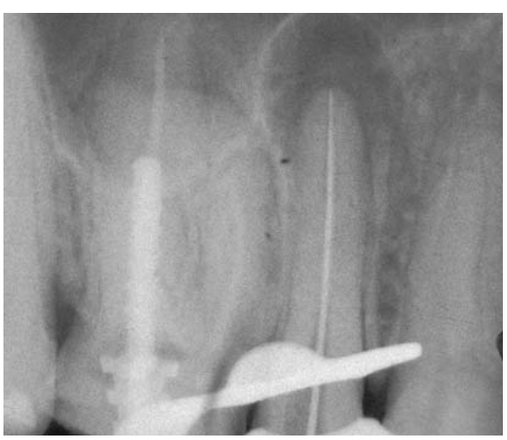
Left: A maxillary second premolar with extensive apical periodontitis.

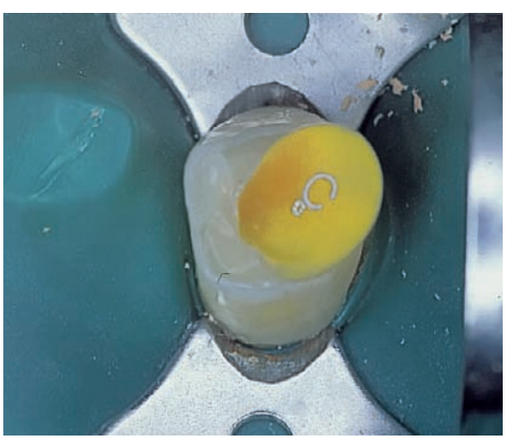
Right: Following root canal instrumentation and irrigation, depot-phoresis treatment was also carried out. The follow-up radiograph shows a significant reduction in the size of the periapical lesion.

25.33 Depot-phoresis

Left: One year following depot-phoresis treatment a periradicular lesion is clearly visible, and the patient complained of severe pain.

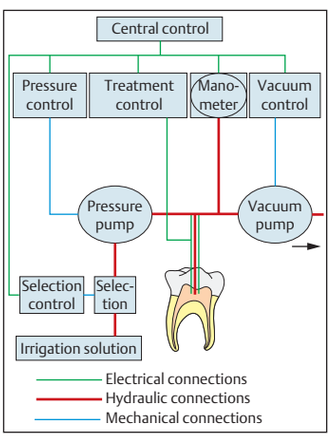
Right: On opening the pulp chamber, pus drained from the massively infected root canal, despite previous depot-phoresis treatment.

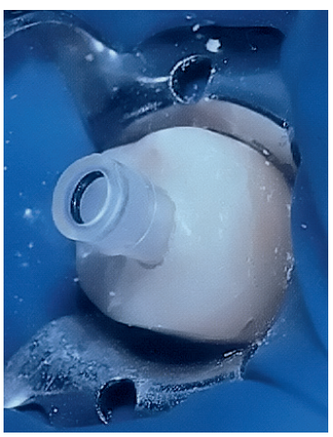


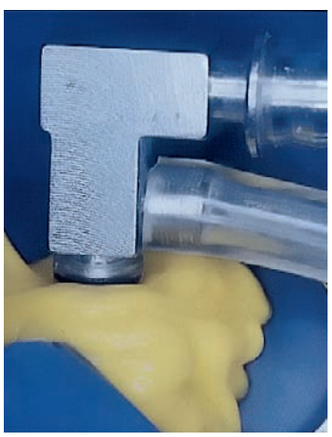


- NIT (noninstrumentation technique): Opinions vary as to the cleaning effect of the vacuum technique developed by Lussi, questioning its suitability for clinical use. Because of still unresolved technical problems, the device is not yet commercially available.
- Laser: Dental lasers have been shown to cause a reduction of the bacterial load, but dentinal cracks, periapical necrosis, and ankylosis have also been described. The extremely thin fiber systems do not usually allow uniform instrumentation of the lateral root canal wall, and also fracture easily. Superiority over conventional rinsing techniques has not been demonstrated.
- Ozone: Although an antibacterial effect on planktonic microorganisms (*E. faecalis*) has been reported, even after 3 minutes of application, ozone has been shown to have no effect against bacteria within a biofilm. A 5% sodium hypochlorite solution, on the other hand, was significantly more effective (Hems et al., 2005).

Other disinfection techniques (e.g., depot-phoresis) have not been shown to be applicable for endodontic therapy (Hülsmann et al., 2006).





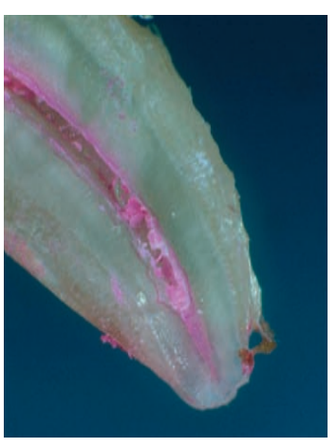


25.34 NIT (according to Lussi)

Left: Schematic illustration of the Lussi technique.

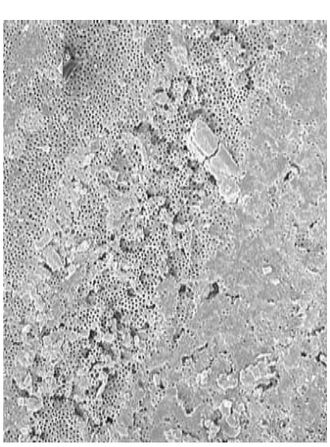
Middle: Within a tightly fitting core build-up, an access cavity has been prepared to create a vacuum within the endodontic system (courtesy of T. Attin).

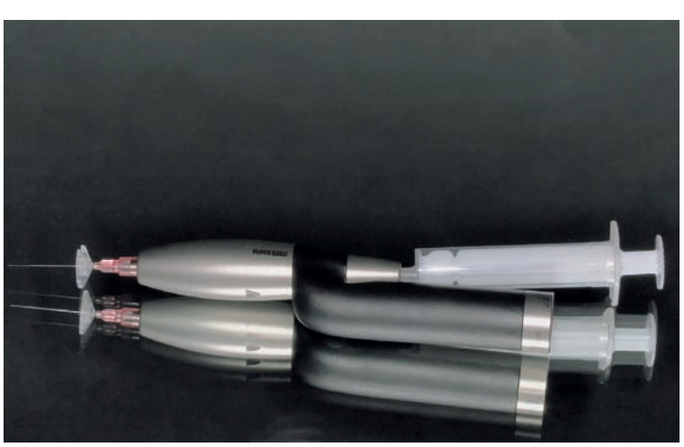
Right: Connection between the vacuum pump and the connector element.



25.35 NIT

The longitudinal sections reveal the massive collection of debris and tissue remnants following NIT treatment (courtesy of T. Attin).





25.36 RinsEndo

The RinsEndo system works through variations in oscillating pressure that pump sodium hypochlorite into the root canal system.

Left: Root canal wall following RinsEndo treatment (courtesy of Dr. Muselmani, Jena).

Possible Adverse Effects of Root Canal Irrigation

Owing to their tissue-dissolving effects, irrigants used for endodontic disinfection may also elicit a variety of, and in some instances serious, adverse effects:

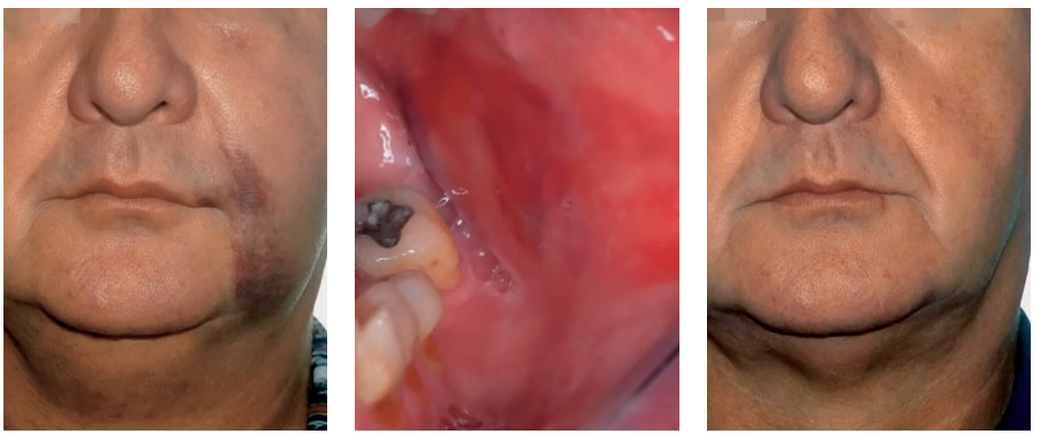
- Sodium hypochlorite: The extent of an injury increases with the concentration of the solution (5.25% sodium hypochlorite is a common household bleach!). Droplets of the irrigant or concentrated aerosol spray which may splash onto the patient's clothes during the use of ultrasonic devices often cause small areas of discoloration of the fibers due to its corrosive effect. Minor irritation will occur following contact of sodium hypochlorite solution with the facial skin or oral mucosa. Depending on the extent of the contact, this will cause temporary itching of a more or less severe nature, which will usually disappear after a short time. The unintentional injection of sodium hypochlorite solution into the periapical tissues due to wedging of the irrigation needle or excessively high pressure in teeth with a wide open foramen or root resorption, will result in: immediate severe pain, which may persist for an extended period edema; and swelling of the adjacent facial region, possibly extending over the entire half of the face, nasolabial angle, eyelid, and upper lip; profuse interstitial hemorrhage with hemorrhagic edema of the facial skin (ec-

25.37 Adverse effect following irrigation with sodium hypochlorite

Left: Extraoral view following irrigation with 3% sodium hypochlorite. The left infraorbital region is clearly swollen as well as the entire left cheek down to the mandible.

Middle: In the intraoral view, the ecchymosis of the buccal mucosa is clearly visible.

Right: Extraoral view following improvement of clinical symptoms.

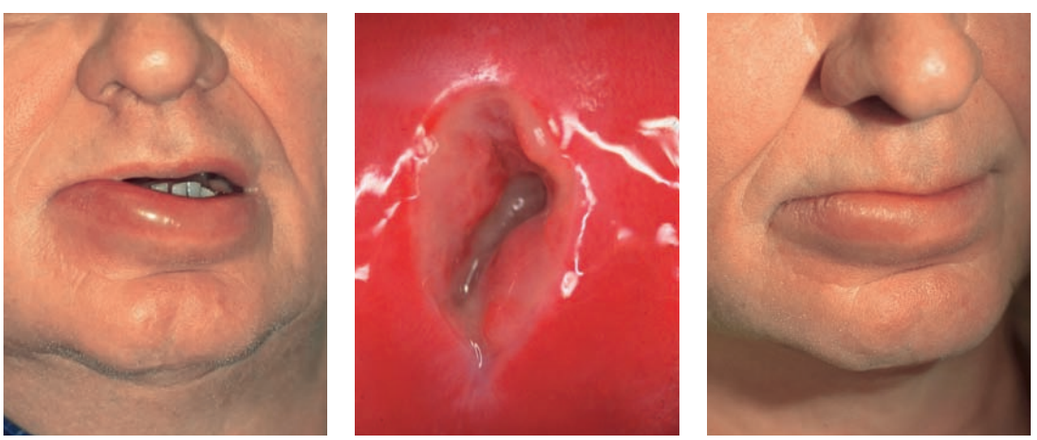


25.38 Adverse effect following irrigation with sodium hypochlorite

Left: Massive swelling of the lower lip following sodium hypochlorite injection through a root perforation to tooth 41.

Middle: Ulcer on the right lower lip 1 week postoperatively.

Right: Extraoral view following reduction of the swelling and ulceration. One year later, the patient still complained of paresthesia in the lower lip area.



chymosis); limited tissue necrosis; and even anesthesia or paresthesia (Hahn and Hülsmann, 2000).

- Hydrogen peroxide: Transapical injection of hydrogen peroxide will cause painful tissue expansion due to gas formation and with an increase in pressure (tissue emphysema). Typically a light crepitus is elicited in the affected tissue.
- Chlorhexidine: This is regarded as exceptionally biocompatible.
- EDTA: There are no reports of adverse effects using EDTA.
- Allergies: There have been isolated reports of allergic reactions to endodontic irrigants, especially sodium hypochlorite, as well as to hydrogen peroxide, chlorhexidine, formalin, and iodine-containing irrigating solutions such as EDTA.
- Compressed air: While drying the root canal using pressurized air, subcutaneous emphysema can occur. It remains unclear how new systems such as NIT or RinsEndo should be evaluated concerning this issue.

25.39 Adverse effect during irrigation with hydrogen peroxide and use of compressed air

Left: Swelling of the right infraorbital region following transapical injection of hydrogen peroxide (3%) during root canal instrumentation of tooth 14. The swelling occurred immediately after the injection and the solution exited above the right internal angle of the eye. Typical tissue crepitus occurred during the following days (courtesy of Prof. Löst).

Right: Emphysema after drying the root canal with compressed air (courtesy of Dr. Schönbach).

25.40 Discoloration of clothes following splashing with sodium hypochlorite

Unintentional splashing on the patient's shirt with sodium hypochlorite solution during endodontic therapy caused this staining.

Mechanical Irrigation with RinsEndo

Simultaneous mechanical irrigation and evacuation of fluids from the root canal was suggested as early as in the 1930s by Seidner (Koçkapan, 2003). However, histologic examinations have shown that the periapical tissues can be damaged by high-suction evacuation mechanisms (Seidner, 1935).

Further development in the area of mechanical root canal irrigation was the creation of a low pressure area within the canal to remove irrigating solutions. The identification of serum in the apical third of the canal was evidence of periapical tissue irritation (Prader, 1947).

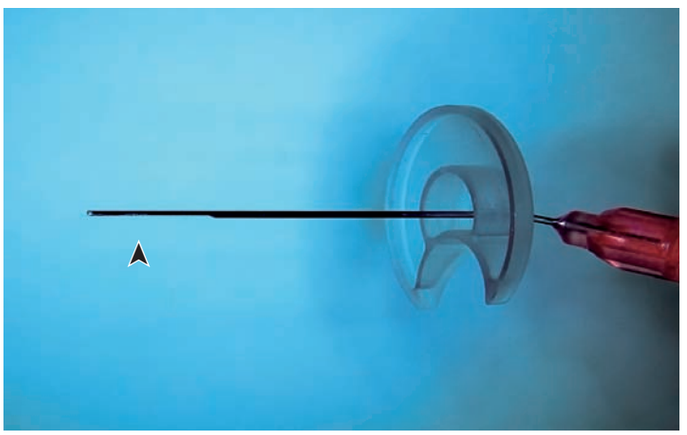
The newest hydrodynamic root canal rinsing system — RinsEndo — operates on the principle of a pressure-suction technique to activate the irrigating solution for improved removal of microorganisms and tissue debris. RinsEndo consists of a handpiece, a single-use disposable cannula (0.45 × 28 mm) and a single-use syringe with a Luer Lock connection. The cannula with a specially shaped 7-mm-long aperture is attached to the handpiece. The cannula has a plastic protective cover, which prevents splashing of the irrigating solution. The cover has a half-round notch for positioning the evacuation device. Within the handpiece itself there is a pneumatic oscillator, a mixing chamber, and a turbine connection.

25.41 RinsEndo system

Root canal irrigation system with a mounted irrigating tip and protective casing. For clinical use of the device, the turbine clutch must be engaged. The irrigating solution is introduced by attaching a single-use syringe system.

25.42 Irrigating tip and protective covering

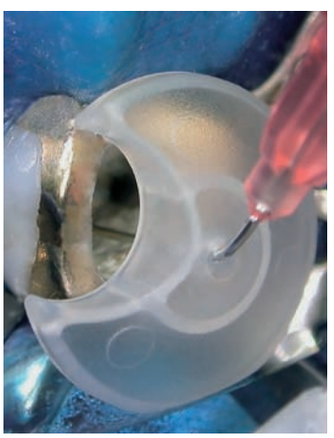
The irrigating tip of the system consists of a specially shaped cannula for this purpose: the lower third of the cannula expels the fluid in a lateral direction (arrow). This design of the aperture avoids both excess pressure and blockage in the apical sections of the canal.



25.43 Use of the protective covering

Left: After insertion of the irrigating cannula, the protective covering is adjusted for irrigating the canal through the coronal access cavity.

Right: The half-moon shaped cut-out of the protective cover permits continuous evacuation of irrigating fluid and therefore continuous renewal with fresh irrigating solution.



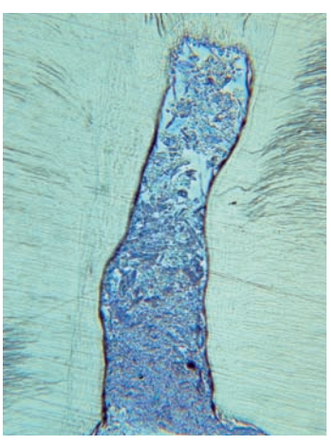
Via a special adaptor, the device can be connected to all conventional handpiece couplings. Following attachment, all water lines and light circuits are automatically closed, thus permitting completely sterile intraoral use. The device is operated by a foot pedal.

The working principle is based on a pneumatically driven oscillator, which delivers 65µL of irrigating solution with a frequency of 1.6 Hz from the cannula into the root canal. Immediately following this step, the second function is the evacuation of part of the fluid volume. For the subsequent fluid exchange, this is replaced in the mixing chamber with fresh irrigating solution. The entire hydrodynamics of the irrigating procedure is enhanced by the simultaneous evacuation of fluid via a suction device positioned in the notch in the protective stopper.

Evacuation and pressure cycles alternate at the rate of about 100× per minute. With this sequence, the volume of fluid exchange is about 6.2 mL/min. The device permits effective use of any solution typically used in endodontic therapy.

25.44 Preparing the RinsEndo system

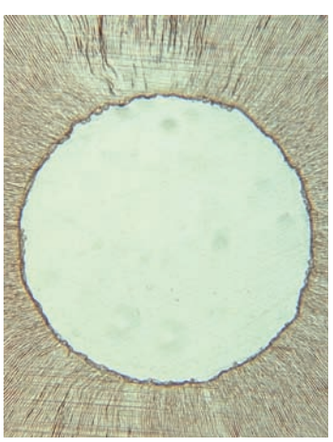
Using a disposable syringe that is attached above the turbine coupling, the desired irrigating solution is injected.



25.45 Cleansing effect in non-mechanically instrumented sections of the root canal

Left: Histologic section of an accessory root canal following use of the RinsEndo system. Even in non-mechanically instrumented areas, there is virtually no tissue debris.

Right: In this section of a portion of a root canal that could not be mechanically instrumented, use of conventional irrigating techniques did not remove all the tissue debris and remnants in the canal (magnification ×40).



25.46 Cleansing effect within the root canal lumen

Left: Histologic section of a root canal following use of the RinsEndo system: the canal lumen is virtually free of debris.

Right: Root canal following use of a conventional 5-mL injection. Note the presence of canal tissue remnants attached to the canal wall in some areas (magnification ×40).

Endox

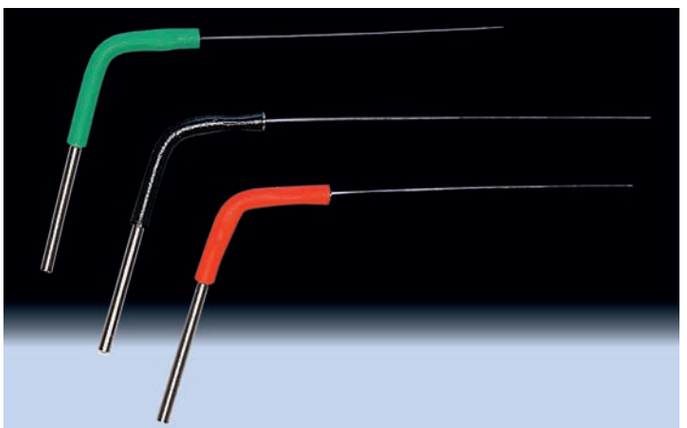
In the early days of dentistry, heated probes were used to eliminate organic material from the root canal. Such untargeted heat has been replaced in the Endox system by a heat-development device targeted toward organic material.

Mechanism of Action

The Endox device creates an alternating current with a base frequency of 312.5 kHz that is applied for 120 ms on the electrode within the root canal (voltage impulse). Depending on the setting of the tooth selector switch and the boost switch, a maximum current of 1040 V and output up to 110 W can be achieved.

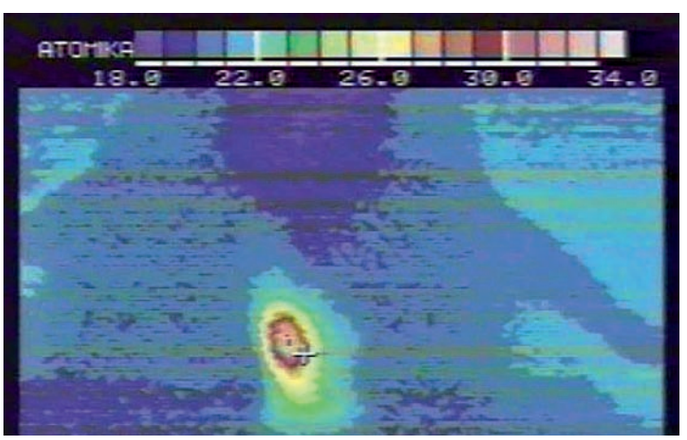
The electrical circuit is closed via a hand electrode and the active, thin wire electrode in the handpiece. The heat created by the Endox system is different from, for example, a "soldering iron," as it is limited to the area of intended effect and only when the presence of organic material leads to a higher level of electrical conductivity.

An integrated apex locator blocks the impulse release in cases of over-instrumentation. The point at which the measurement is taken is intentionally about 1.5 mm shorter than the actual apex (Endox-Apex-Point).



25.47 The Endox instrument

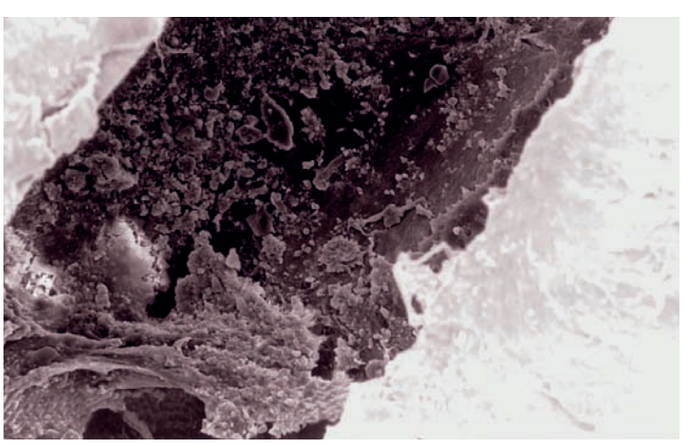
Endox electrodes, green = apex locator, diameter 0.15 mm, red = 0.15 mm, black = 0.20 mm.



25.48 Temperature development

Thermographic investigations have demonstrated that in a radius of 2.5 mm around the tip of the electrode, electrical pulses of over 800 °C develop.

Right: With the Endox device, the electrical circuit is completed via a hand electrode and the active electrode in the instrument's handpiece. The electrical pulse is applied using a foot pedal.



25.49 Effect within the root canal

Scanning electron microscopic (SEM) image (magnification ×360) of a root canal. Histologic investigations have demonstrated that organic tissues are vaporized within a 2.5-mm radius around the tip of the electrode. The only remnants are sterile ashes but the dentin remains unaltered. Beyond the area of effect (lower sections of the canal in this image) tissue viability is maintained.

Clinical Application

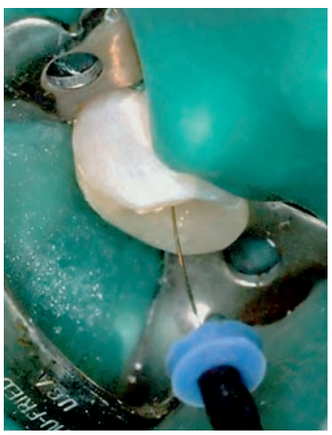
Following access to the pulpal cavity and removal of the coronal pulp soft tissues, the largest electrode that can pass to the Endox-Apex-Point is selected. For this procedure, it is often not necessary to perform canal instrumentation. The clinically tried and tested procedure is to deliver one impulse at one-third and one at two-thirds of the canal length, and three impulses at the apex point.

If no electrical contact is established, as in cases of pulpal necrosis or endodontic retreatment, the root canal should be flushed with physiologic saline solution and briefly dried.

Scientific Data

Basically it is quite difficult to simulate the Endox function in a laboratory environment. In vitro studies in which the entire root was embedded in a gel substance, have found comparable microbial reduction with the KEY-II-Laser and conventional sodium hypochlorite irrigation. Clinically, a similar effect was achieved by Endox but usually without any previous mechanical instrumentation.

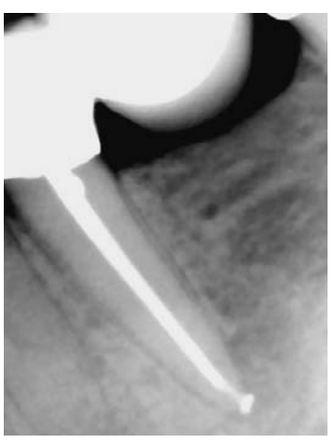
In a study of Wistar rats, 21 vital maxillary molars were opened and treated with the Endox system without any additional instrumentation of the root canals. Histologic examination revealed that the root canals were completely free of soft tissue.



25.50 Pulpal symptoms

Left: Pulpal symptoms on tooth 15.

Right: The patient was free of pain following Endox treatment. Clinical studies have shown that this effect is a routine result, but it is possible that electrophysiologic processes are responsible for such results.



25.51 Apical osteolysis

Left: Apical osteolysis in relation to tooth 35.

Right: Complete healing of the apical lesion 3 months after root canal filling.

In a similar simulation, data evaluation by means of a thermographic camera demonstrated noncritical heat development in the periodontal region, which was comparable with that produced by the KEY-II-Laser. A study of the System-B concept revealed that temperature pulses up to 360 °C elicited mild inflammation in the periodontium, which disappeared, however, after 12 hours. The Endox-pulse of 120 ms is considerably shorter.

In a study of the initial treatment of acute pulpitis in 60 patients, the use of the Endox device was compared with a regimen including instrumentation up to ISO size 35 and 20 minutes of irrigation with sodium hypochlorite. Immediately after the local anesthesia wore off, as well as 24 and 48 hours later, significantly less discomfort was reported in the Endox group.

In a randomized clinical trial including 239 patients, a traditional endodontic regimen including stepback hand instrumentation, sodium hypochlorite irrigation, and lateral compaction of gutta-percha was compared with a “short” treatment including ISO size 25 hand instrumentation, Endox treatment, and Thermafil obturation. The Endox procedure shortened the clinical treatment time by an average of 50%, however, 6 years after the study there were no clinical or radiographic differences between the two groups.

Electrochemically Activated Water (ECA)

McDonnell et al. (1999) demonstrated that hypochlorous acid has a higher antimicrobial effect than sodium hypochlorite. ECA is produced via electrochemical energy change (electrolysis) of a weak saline solution. Hypochlorous acid is formed at the anode and sodium hydroxide at the cathode. At a pH value of about 6, the saline solution becomes a pure hypochlorous acid, which can be used for root canal disinfection.

Hypochlorous acid has considerably less cytotoxic effects than sodium hypochlorite. It has an oxidizing effect with a neutrophil-like pattern of action, and is also disinfectant via the potential inactivation of the polysaccharide protective layer of the biofilm.

In general medicine, this method is routinely used for the treatment of chronic wounds and for endoscope disinfection.

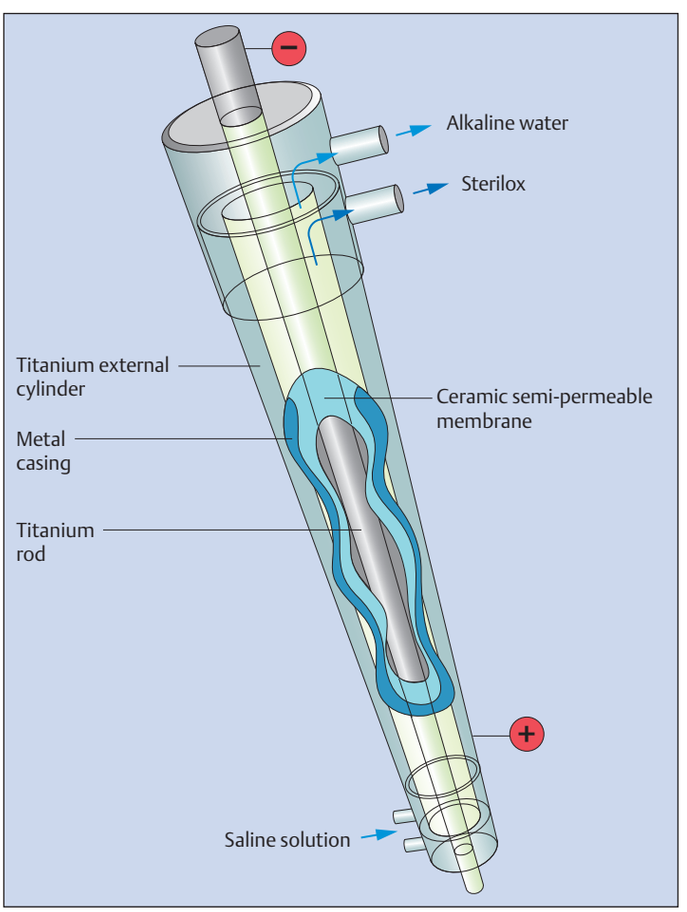
In industrial production, lead is an undesirable byproduct of electrochemical activation. The dental Sterilox generator (Sterilox Dental, PuriCore, PA, USA) avoids this adverse effect by using titanium electrodes and only using purified salt in the process.

25.52 The dental Sterilox generator

To produce hypochlorous acid, the container is filled with a low-concentration saline solution. The required amount of AquatineEC Endodontic Cleanser is produced directly by activating the device. In comparison to the amount of hypochlorous acid, a significantly smaller amount of sodium hydroxide is produced at the same time and fed into the lower container. The solutions can be stored in tinted containers in a refrigerator for up to 96 hours.

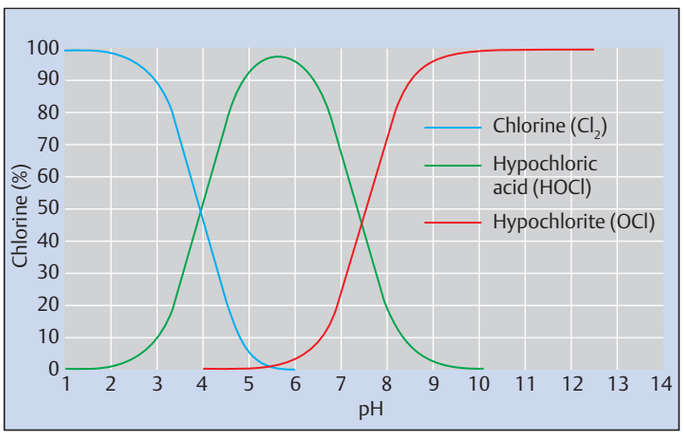
25.53 The Sterilox cell

The anode and the cathode of the dental Sterilox generator are made of titanium, as is the exterior casing. The membrane is of ceramic origin.



The solution produced at the anode (AquatineEC Endodontic Cleanser) has a pH value of approximately 6. This ensures the production of an almost pure hypochlorous acid with maximal disinfection properties. Garcia et al. (2006) as well as Sampson et al. (2006) demonstrated that the AquatineEC Endodontic Cleanser combined with EDTA is successful in root canal disinfection and removal of any smear layer. AquatineEC has received approval from the US Food and Drug Administration (FDA) as an irrigating solution for the disinfection of root canals.

AquatineEC completely replaces sodium hypochlorite in clinical application, and is used in the usual irrigating sequence with EDTA, citric acid, and chlorhexidine. Activation of the hypochlorous acid via ultrasound appears to potentiate its antibacterial effect. Because of its detergent effect, the sodium hydroxide solution emanating from the cathode can be used alternately with AquatineEC to remove the smear layer. To increase the efficiency of the process, additional ultrasonic activation has been recommended.



25.54 Products of electrolysis of saline solution

Salt water electrolysis results in production of primary substances such as chlorine, hypochlorous acid, and hypochlorite. Various and varying pH values regulate the concentrations of the individual components in the end product. At a pH value of approximately 6, the substance produced most is hypochlorous acid (approximately 96%).

25.55 Clinical case

Left: The radiograph reveals periapical radiolucency around tooth 36.

Right: The tooth was treated endodontically in a single visit. The canal was irrigated with AquatineEC Endodontic Cleanser, activated ultrasonically. The definitive root canal filling was done using warm vertical compaction.

25.56 Clinical case

Left: Follow-up, 6 months later.

Right: Follow-up, 18 months later. The periapical radiolucency has completely resolved and the extruded sealer has been almost completely resorbed.

Photo-activated Disinfection (PAD)

Photodynamic therapy has been in use for many years in general medicine. The treatment involves the use of photosensitive substances and light.

Photosensitive substances are light-sensitive materials that are stimulated photochemically via appropriate light wavelengths and intensity and therefore react with other chemical substances. In dentistry, the concept has been used for many years to combat periodontal microflora (aPDT, Helbo, Grieskirchen, Austria). Among other compounds, dye pigments are used as photosensitive compounds (e.g., tolonium chloride or methylene blue).

The targeted release of photosensitive solutions within the root canal leads to their accumulation within the intracanal microorganisms. The dye has a concentration of less than 20.0 µg/mL at a pH value of 5.25 (buffered by the addition of sodium phosphate).

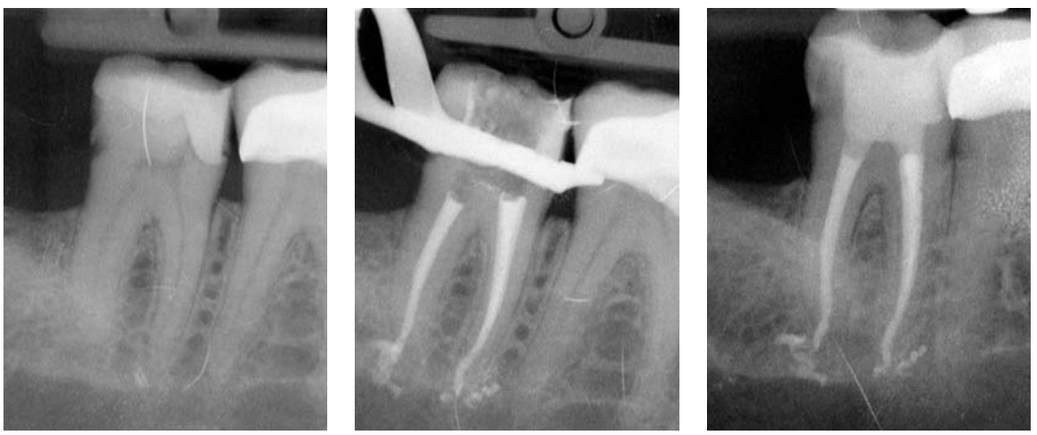
Activation of the photosensitive substances is by means of a diode laser with 4 W/cm^2, which leads to illumination with a specific wavelength 633 ± 2 nm. Following successful illumination, the integrity of bacterial membranes appears damaged by the dye (Williams et al., 2004, 2005).

25.57 Clinical case I

Left: Preoperative radiograph of the mandibular second molar exhibiting signs of irreversible pulpitis.

Middle: Intraoperative radiograph of the completed root canal filling following canal disinfection using PAD.

Right: Radiographic appearance of the final endodontic treatment and the coronal adhesive seal and restoration.



25.58 The Aseptim-(SciCan) laser

Left: The endodontic attachment is a flexible cylinder with a length of 15 mm and a diameter of 400 nm. Seventy percent of the light is emitted radially and 30% at the tip. The dye has a concentration of less than 20.0 µg/mL, at a pH level of 5.25 (buffered with the addition of sodium phosphate).

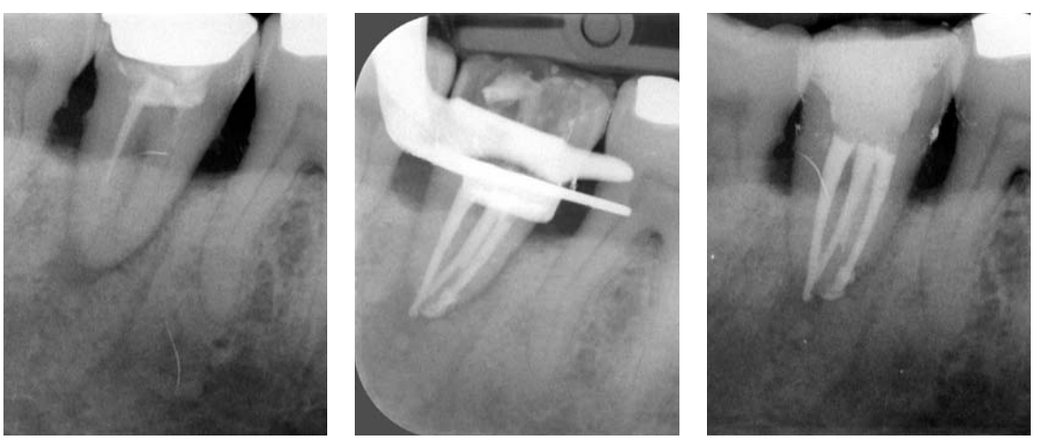
Right: Clinical tip with PAD solution and microbrush for application.

25.59 Clinical case II

Left: The radiograph depicts an inadequate root canal treatment and a secondary periapical lesion.

Middle: Intraoperative radiographic check.

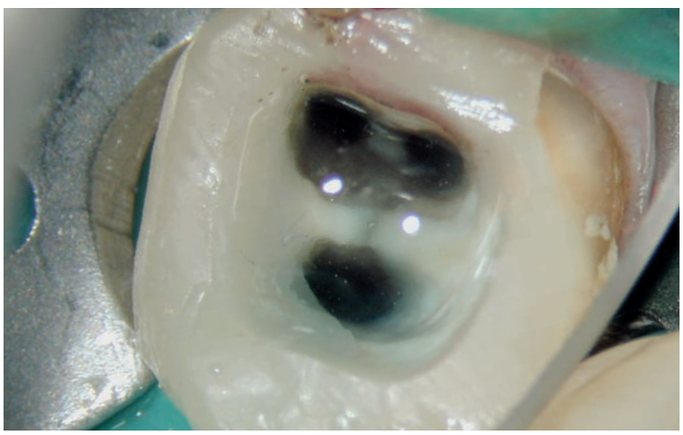
Right: Postoperative radiograph of the retreated root canal showing positive response at the periapical region following effective disinfection with PAD.



In a comparative study, Bonsor et al. (2006) demonstrated that the combined use of PAD and citric acid provided an efficient alternative to the more classic combination of sodium hypochlorite and citric acid. Another in vivo study demonstrated that PAD was also effective as an additional method of disinfection to eliminate positive cultures remaining after traditional irrigation protocols (Bonsor et al., 2006). The efficiency of PAD in both laboratory and natural root canals was investigated by Williams et al. (2006). They demonstrated a species-specific bactericidal effect, irrespective of energy dose.

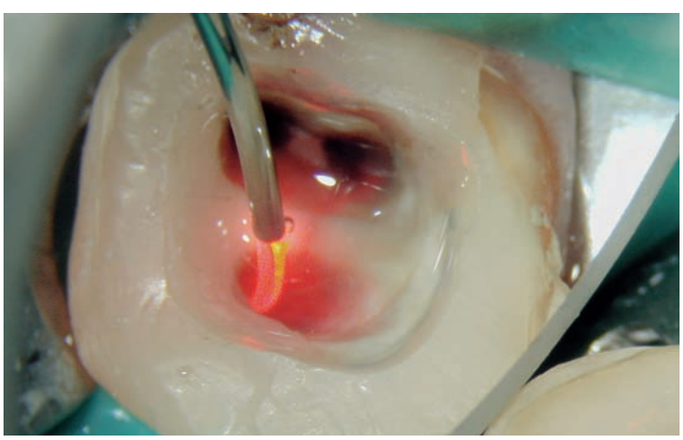
Soukos et al. (2006) investigated the effect of methylene blue (25 µg/mL) with a time of 5 minutes and illumination with red light (222 J/cm^2). The procedure was effective in eliminating 97% of an *E. faecalis* biofilm. The main conclusion was that PAD is effective for endodontic disinfection.

Williams et al. (2006) worked with tolonium chloride (13 µg/mL) as a photosensitive agent, resulting in a reduction in application times.



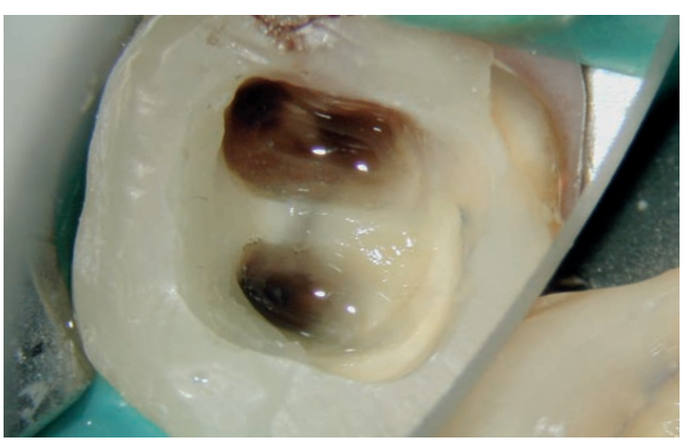
25.60 Step I

Following purely mechanical instrumentation, the root canals were filled with Aseptim solution.



25.61 Step II

In each root canal, the light source was applied for 150 seconds.



25.62 Step III

Following successful photochemical disinfection, a slight discoloration indicates that the solution is still present in the canals.

Ozone

For decades, ozone has been successfully used for water conditioning. With a pH value above 10, ozone-enhanced sodium hypochlorite in contact with organic tissue elicits the following reactions:

- saponification (reaction between fatty acids and sodium hydroxide to form soap and glycerol);
- neutralization of amino acids (reaction between amino acids and sodium hydroxide to form salt and water);
- chloramine reaction (reaction between amino acid and hypochlorous acid to form chloramine and water).

The process is dependent on the availability of free oxygen radicals (Spickett et al., 2000).

The efficacy of sodium hypochlorite, even at low potency, is accelerated by ozone, significantly reducing the required contact time.

25.63 HealOzone generator

Left: The HealOzone generator (KaVo Dental, Biberach, Germany) in its second generation was developed with particular attention for use in the disinfection of root canals.

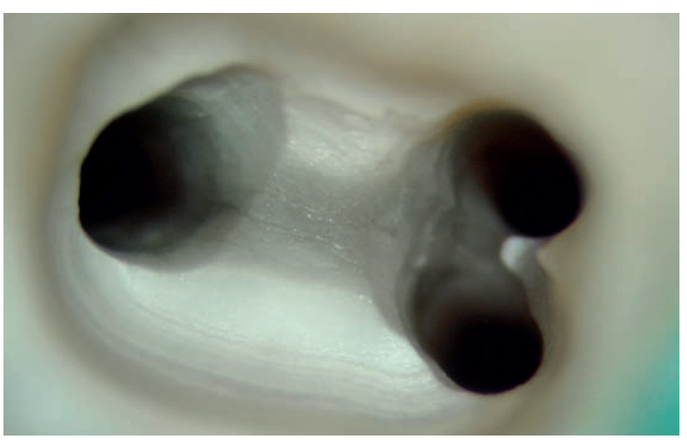
Right: This cross-sectional view demonstrates the positioning of the handpiece on the coronal section of the tooth, the cannula inserted into the canal, and the silicone cap that seals the coronal aspect.

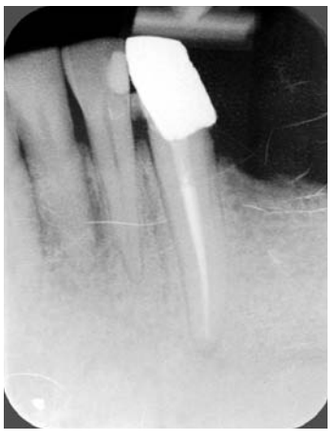
25.64 HealOzone handpiece

HealOzone handpiece with the vacuum caps (shown here are the elongated versions for endodontic therapy) and the various sterilizable cannulas.

25.65 Prerequisites

The ozonization of sodium hypochlorite using the HealOzone generator and cannulas can only be successfully performed with well-shaped access cavities and adequate root canal access.





25.66 Clinical case I

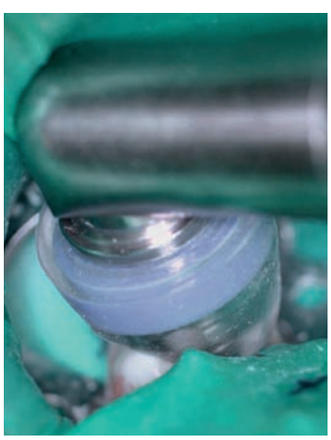
Left: The radiograph clearly depicts a periapical radiolucency in relation to tooth 33. A single-visit retreatment was carried out, which included irrigation with multiple ozonized sodium hypochlorite. The root canal fillings were carried out with warm vertical compacted Resilon.

Middle: Follow-up radiograph 6 months later.

Right: Twelve-month follow-up radiograph showing almost complete healing of the periapical lesion.

25.67 Creating a vacuum

The silicone cap isolates the access cavity, thus creating the necessary vacuum.



25.68 Clinical case II

Left: Preoperative tooth 46: an interradicular radiolucency is clearly visible.

Right: Irrigation with HealOzone. The canals were partially filled with sodium hypochlorite; the cannulas were inserted into each canal, the silicone cap was positioned coronally and supported, and the generator was activated for 120 seconds.

25.69 Clinical case II

Left: Follow-up radiograph following a backfill endodontic procedure. All three canals were “patent,” and this led to some periapical extrusion of sealer following warm vertical compaction.

Right: Twelve months after endodontic treatment, the interradicular radiolucency appears completely healed and the periapically extruded sealer has been at least partially resorbed.

Noninstrumentation Technique (NIT)

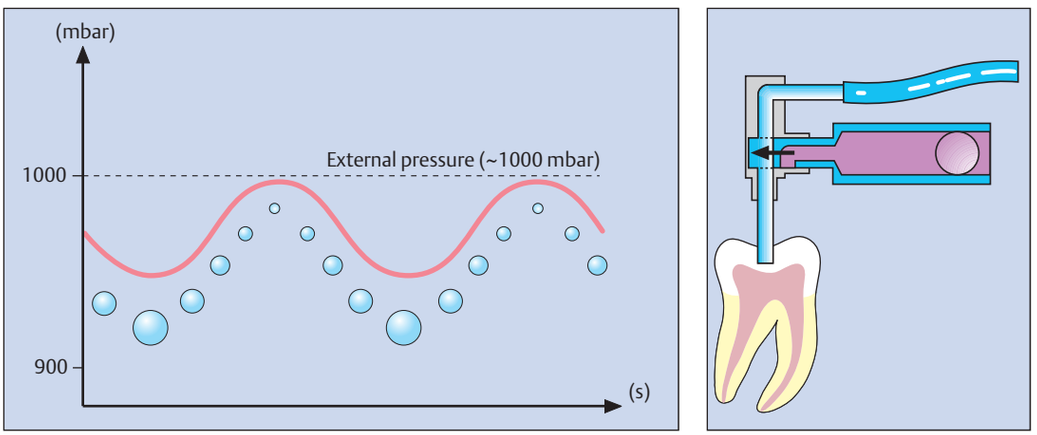
Cleansing

NIT is a new, completely automated method, in which the entire root canal system can be accessed, instrumented, and filled without the use of conventional instruments for mechanical instrumentation (Lussi et al., 1993; Portmann and Lussi, 1994; Lussi et al., 1995c). For root canal cleansing, the pulp chamber is opened coronally and connected tightly and securely to the apparatus. The process of cleansing occurs under alternating but always negative pressure, which causes the formation of bubbles that subsequently implode (cavitation). This process occurs up to 250 times per second and elicits an intensive exchange of the cleansing fluid (sodium hypochlorite) within the entire endodontium. The sodium hypochlorite dissolves the pulpal soft tissues and disinfects the entire endodontic system within 10–15 minutes (Barnett et al., 1985; Baumgartner and Cuenin, 1992). The bubbles have a maximum diameter of 50 µm and lead to the distribution of sodium hypochlorite within the entire root canal system. The negative pressure prevents penetration into peripheral periapical tissue.

25.70 Mechanics of the fully automated cleansing system

Periodically alternating negative pressure leads to the formation of bubbles, which subsequently implode. This process leads to hydrodynamic turbulences causing an active fluid exchange. The negative pressure prevents penetration of the irrigating solution into the periapical tissues.

Right: A system of motor-driven processes regulates pressure alterations within the endodontium.

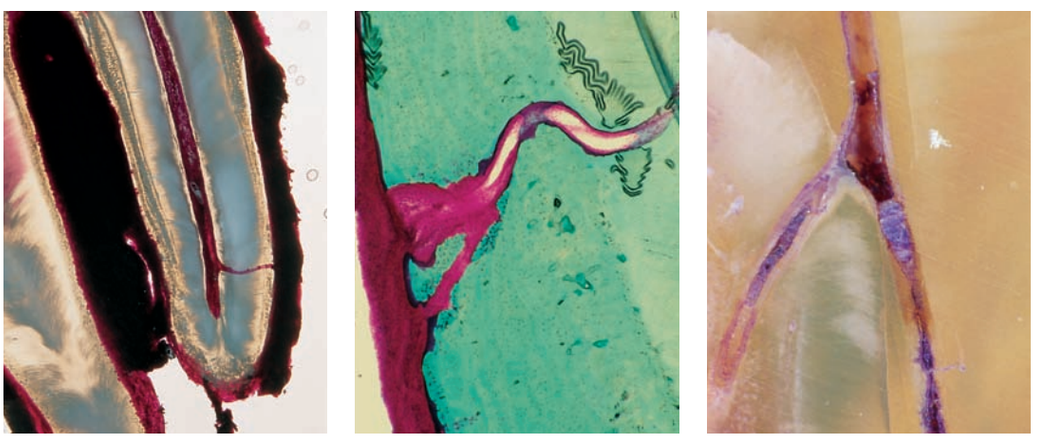


25.71 Anatomy of the endodontium with lateral canals (without NIT)

Left: Histologic section showing a lateral accessory canal near the apex.

Middle: Magnified histologic view of the lateral canal reveals granulation tissue, cementum, and root dentin.

Right: The incompletely instrumented root canal treatment led to pain and finally to extraction of the tooth.



25.72 Vertical section of an instrumented root canal (with NIT)

Left: Pulp stones do not impede or prevent instrumentation. The turbulences allow fluid exchange, even beyond an obstruction.

Middle: Well-cleansed apical delta. However, tissue remnants still persist in the lateral accessory canal.

Right: SEM image revealing the calcifications and open dentinal tubules. There is no visual evidence of a smear layer.

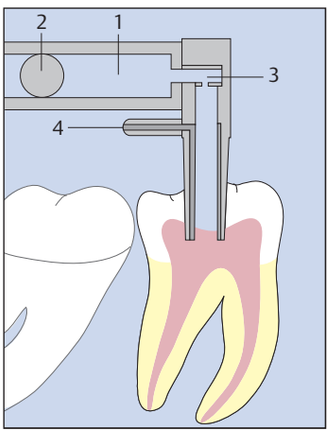
Obturation

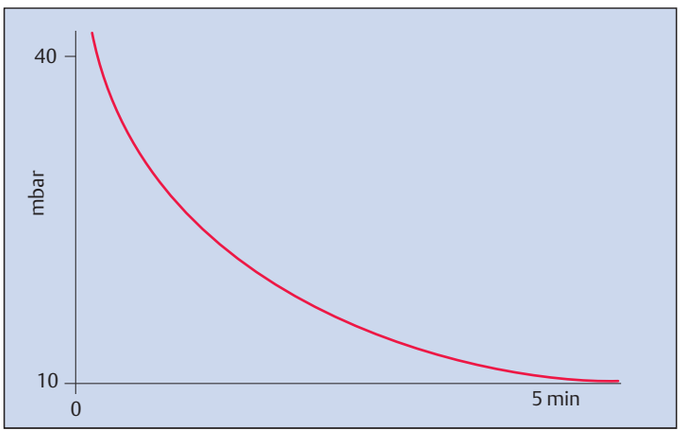
Using the NIT cleansing method as described by Lussi et al. (1993), no dentin is removed from the root canal walls so there is no weakening of the tooth structure. However, obturation using conventional endodontic techniques is not possible.

With the application of negative pressure of <10 mbar (= 7.5 mmHg), perfect obturation in vitro and in vivo in routine endodontic practice is possible (Lussi et al., 1995c, 1996, 1997, 2002). Once the tube is tightly sealed to the pulp chamber, it is connected to a high-volume vacuum pump. The required negative pressure is achieved in about 10 minutes.

Through the activation of a valve, the delivery device is connected with the root canal system and the filling material is "sucked" into the root canal by virtue of the negative pressure. With due consideration of the possibility of retreatment, subsequent insertion of gutta-percha point is recommended.

Definitive canal obturation has to date only been carried out in patients with conventionally instrumented root canals.

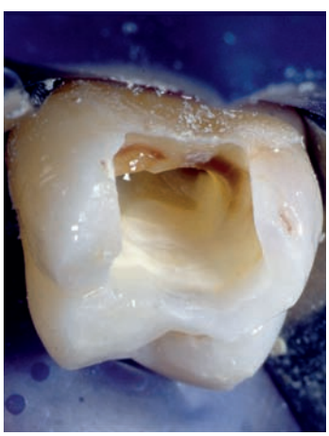




25.73 Vacuum obturation mechanism

A multistage vacuum pump creates a negative pressure field within the endodontium of 10 mbar or less (0 mbar = absolute vacuum; right diagram).

Left: The lower conductor (**4**) leads to the vacuum pump. The reservoir (above, **1**) contains the filling paste, which, after the necessary negative pressure is reached and the valve has been opened (**3**), is used to obturate the entire root canal system. The steel ball bearing (**2**) within the reservoir is necessary to prevent any incursion of air into the system.

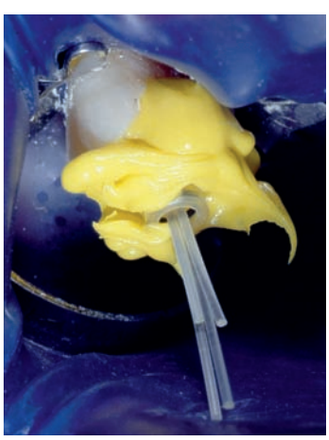


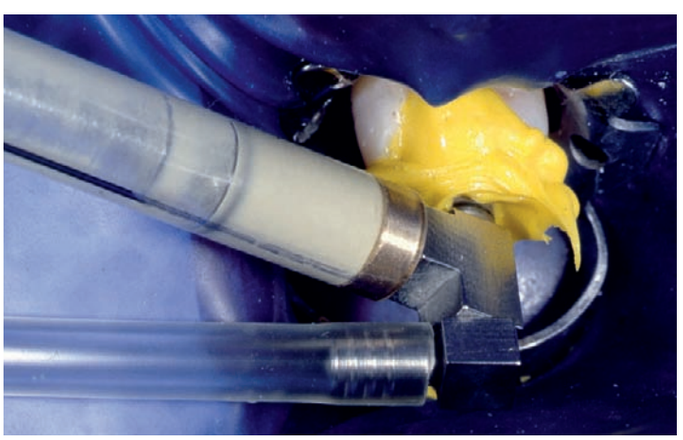
25.74 Tooth preparation

Left: Tooth 16 following complete root canal instrumentation. The calcium hydroxide dressing has been removed and the canals have been dried.

Middle: Nylon threads have been inserted into the four root canal orifices.

Right: An adaptor casing providing a secure connection to the multistage vacuum pump is fitted over the nylon threads.





25.75 Sealing and connecting the tooth to the machine

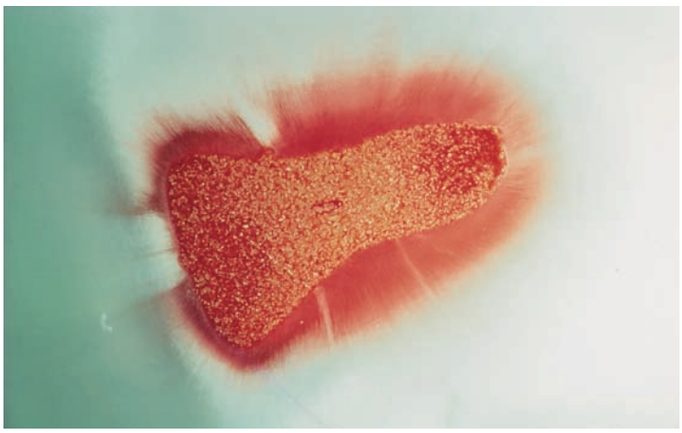
Left: A tight seal and connection between the tooth and the adaptor casing is created with the use of a silicone material.

Right: After the silicone material has set, the vacuum pump tubing and the reservoir can be connected. Once the valves are opened, the root canal filling paste flows into the prepared endodontium. Note that the steel ball bearing above the reservoir has moved slightly to the right.

25.76 Obturated root canal

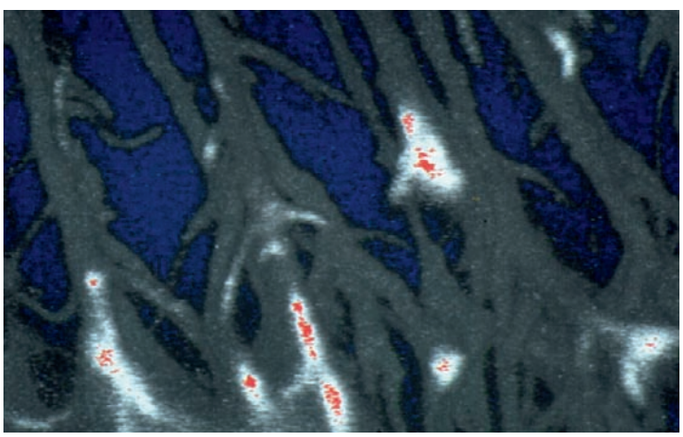
The transverse histologic section through the root canals demonstrates the penetration of the root canal filling paste into the dentinal tubules. This is possible because during the cleansing/instrumentation procedure no smear layer was created (experimental filling paste, stained red).

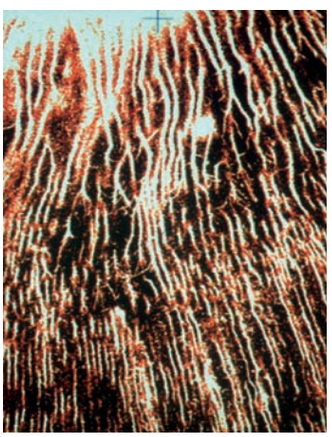
Right: Dense obturation of two oval canals. The anatomy of the root canals was not altered by the cleansing procedure.



25.77 Endodontically filled teeth

Using confocal laser microscopy, penetration into the dentinal tubules and into lateral accessory canals can be observed (experimental filling paste: AH-Plus [Dentsply, PA, USA], with fluorescing dye material) (courtesy of D. Stojan).



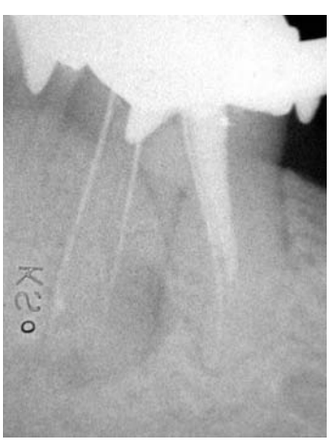


25.78 Clinical case, tooth 36

Left: Incomplete root canal filling and an inadequate composite restoration.

Middle: Apical periodontitis 2 years after crown reconstruction. For financial reasons, endodontic retreatment was not pursued following coronal reconstruction.

Right: Retreatment through the new coronal reconstruction. The screw post in the distal canal was left in situ.

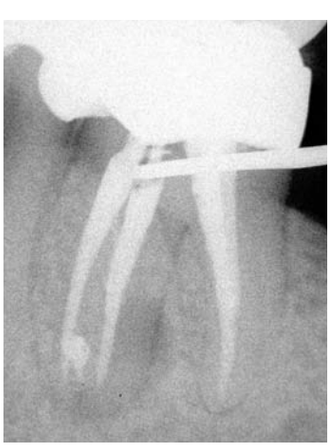


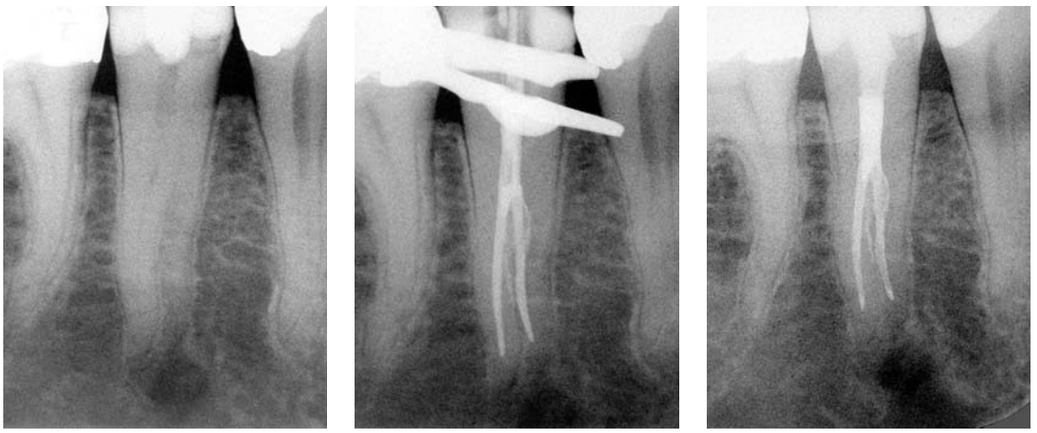
25.79 Clinical case, tooth 36

Left: With the use of vacuum obturation, not only the root canals, but also an internal resorption lacuna was obturated.

Middle: During the insertion of guttapercha points, some root canal filling paste (AH-Plus) was forced through an apical foramen communicating with the internal root resorption.

Right: Follow-up radiograph 20 months later.



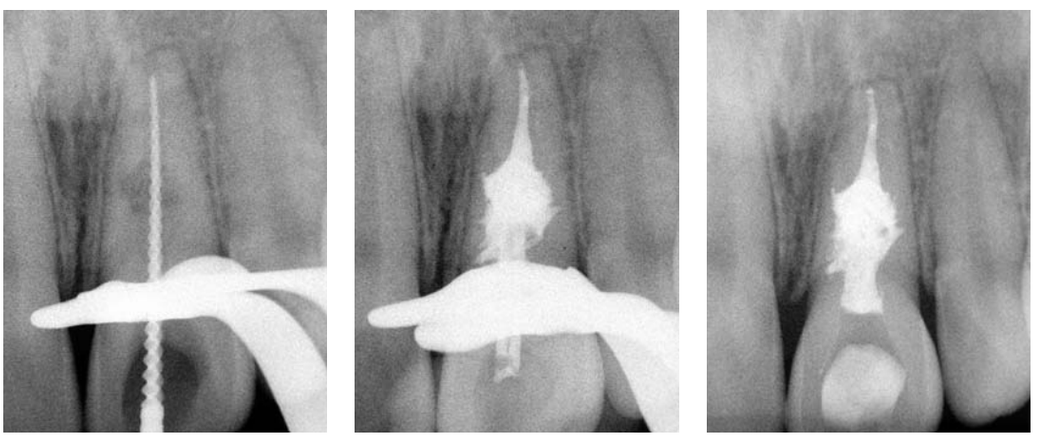


25.80 Clinical case, tooth 45

Left: Two-rooted mandibular premolar following emergency procedure (access cavity and crown-down preparation).

Middle: During NIT obturation, an additional, third, root canal, which remained undetected during manual instrumentation despite the use of a clinical microscope, was also filled.

Right: Follow-up radiograph 1 year later.

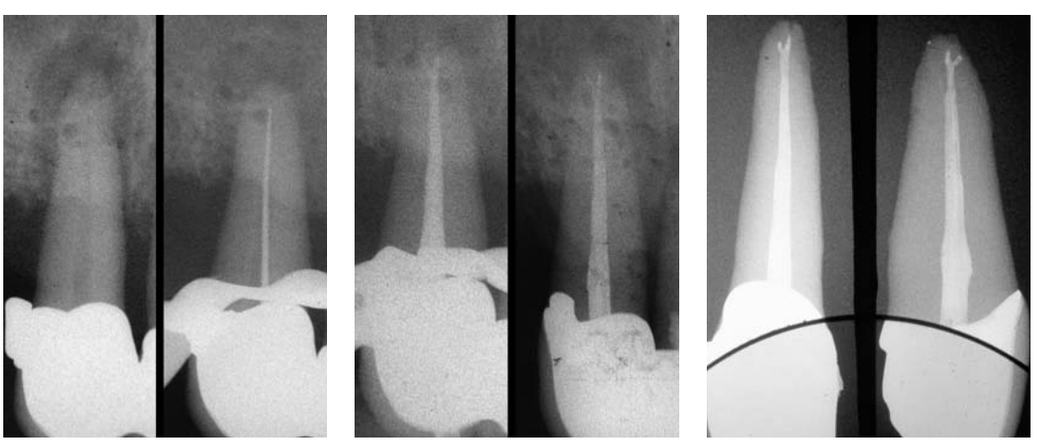


25.81 Clinical case, tooth 21

Left: Internal resorption which allowed only limited instrumentation of the root canal assisted by irrigation.

Middle: NIT obturation was successful in optimally filling the internal resorption lacuna.

Right: Follow-up radiograph after conclusion of the obturation. Due to the insertion of the primary gutta-percha point, there is evidence of slight overfilling.

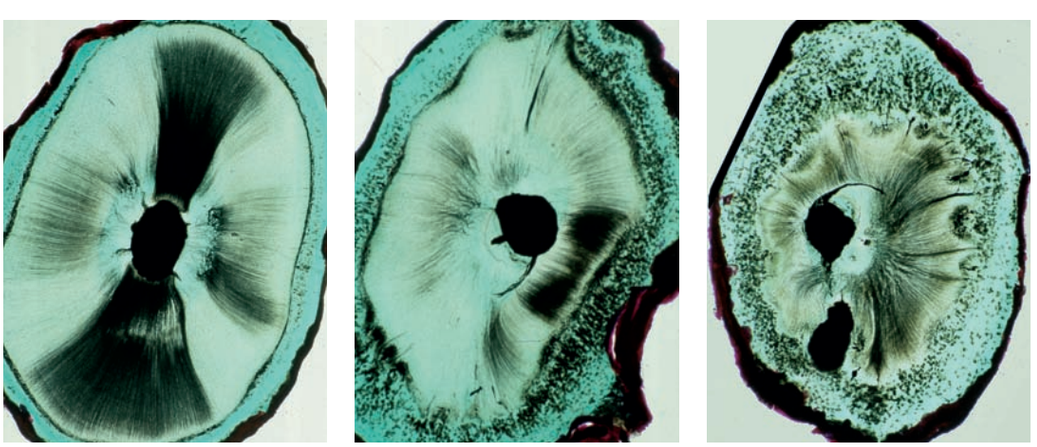


25.82 Clinical case, tooth 13

Left: Tooth 13 before and during endodontic instrumentation.

Middle: NIT obturation and follow-up radiograph 1 year later. Unfortunately, the tooth had to be extracted at a later date for periodontal and prosthetic reasons.

Right: Buccolingual and mesiodistal radiographic views of the extracted tooth.



25.83 Clinical case, tooth 13

Histologic sections of the extracted tooth.

Left: Coronal section of the root canal: well-filled canal lumen. The filling paste is well dispersed into the grooves and dentinal tubules.

Middle: Also in the middle sections of the root canal, the root canal paste is well dispersed into grooves, lateral (accessory) canals, and dentinal tubules.

Right: Well-filled apical delta with filled accessory/lateral canals.

26 Intracanal Dressings

A temporary intracanal dressing is necessary when an endodontic treatment cannot be completed in a single visit because an empty root canal system will be recolonized by bacteria within a short time. In infected cases with pulpal necrosis, the application of an intracanal medication in addition to chemo-mechanical preparation is recommended in order to reduce the number of remaining microorganisms.

However, the extent to which the application of calcium hydroxide might increase the rate of clinical success remains unclear (Sathorn et al., 2007). The current standard medication is an aqueous solution of calcium hydroxide (Rödig and Hülsmann, 2005), but the use of chlorhexidine (CHX) gel or a combination of calcium hydroxide and CHX has been discussed (Rödig, 2006, Turk et al., 2009).

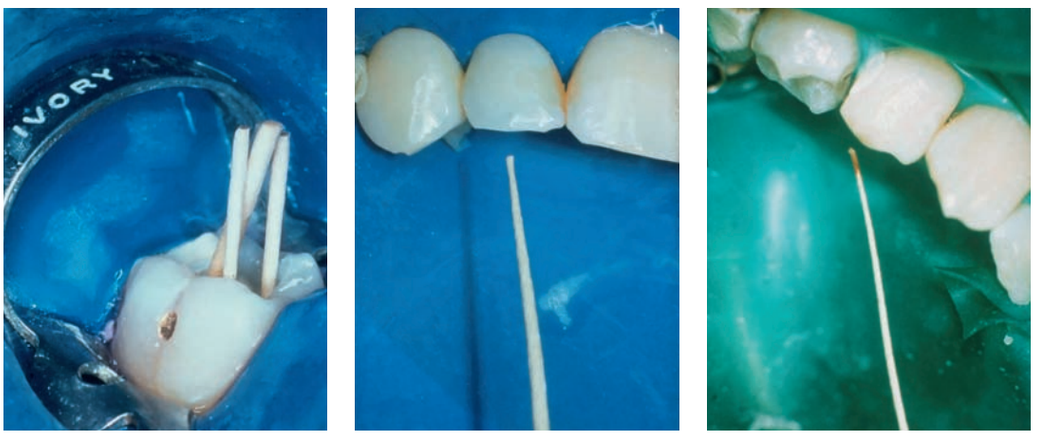
For patients with acute pain, the application of Ledermix (Riemser, Greifswald, Germany) has been suggested, primarily in Europe (this combination of antibiotics and corticosteroids is not available worldwide). The use of chlorphenol-containing dressings is not recommended because these substances have severe cytotoxic effects and exhibit questionable antimicrobial activity.

26.1 Drying the root canals

Left: The standard procedure for thoroughly drying the root canals comprises the repeated use of sterile paper points inserted to working length.

Middle: The dryness of the paper points is assessed by visual inspection and stroking the paper point against a mouth mirror or the rubber dam.

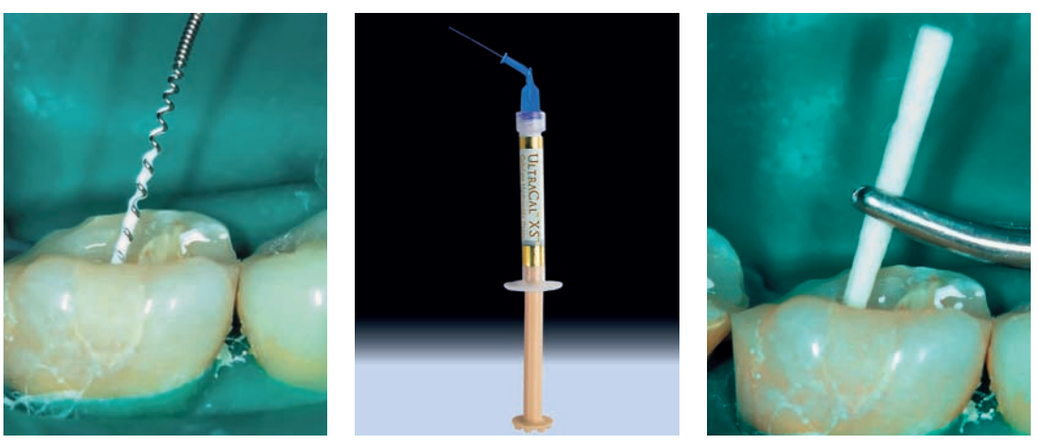
Right: If the withdrawn paper point exhibits any evidence of apical secretions or hemorrhage, a definitive root canal obturation is not indicated at this time.



26.2 Application of the dressing

Left and middle: The placement of the dressing should be performed with a Lentulo spiral or a thin injection needle (Ultracal, Ultradent, South Jordan, UT, USA) which provides application to the apical part of the root canal system.

Right: Following initial application the dressing is compacted apically (courtesy of T. Attin).

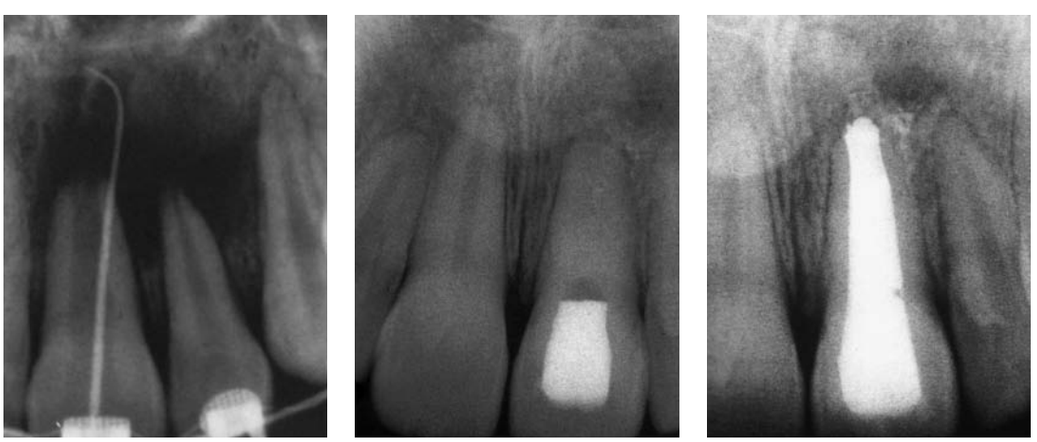


26.3 Intracanal dressing

Left: Preoperative radiograph of a tooth with a wide open foramen and apical periodontitis.

Middle: The correct placement of a dressing can be checked radiographically. The radiopacity of calcium hydroxide is similar to dentin.

Right: Follow-up radiograph taken after root canal obturation. After several applications of calcium hydroxide, a hard-tissue barrier has formed at the apex (apexification) and the periapical lesion has reduced considerably in size.



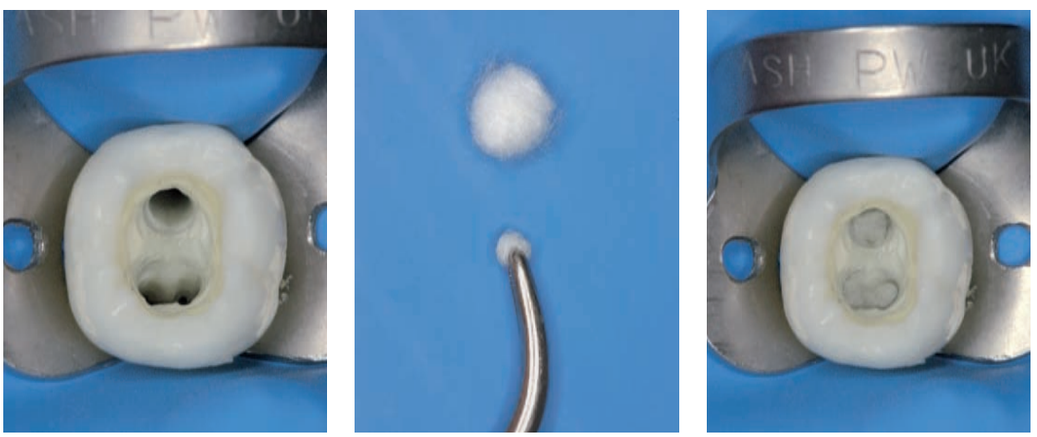
Temporary Coronal Restoration

Bacteria-tight temporary restoration of the access cavity is an important step of any root canal treatment requiring multiple visits.

The importance of a bacteria-tight restoration for successful endodontic therapy has been demonstrated in numerous studies (Ray and Trope, 1995; Tronstad et al., 2000; Hommez et al., 2002; Iqbal et al., 2003). In contrast, Abbott (1994) found that permeable temporary restorations were responsible for persistent postoperative discomfort in 80% of cases. Such restorations also can negatively influence the prognosis of the root canal treatment (Torabinejad et al., 1990).

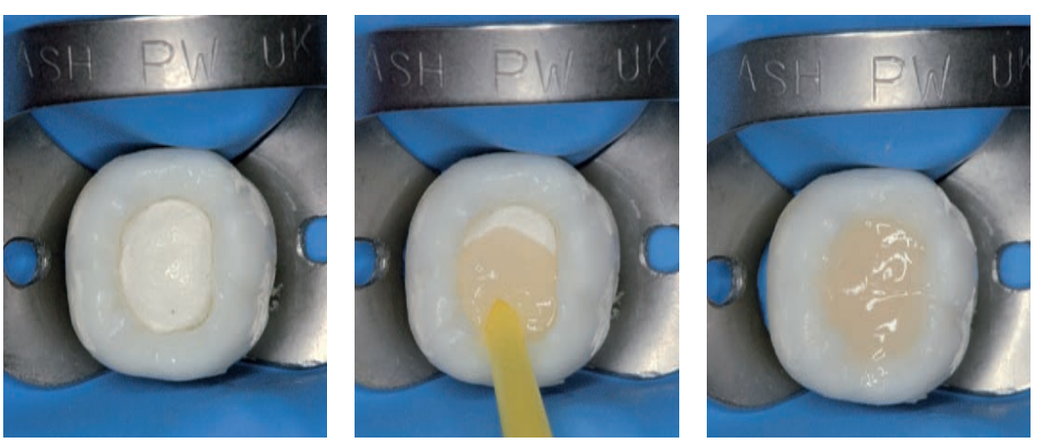
For a temporary coronal restoration, careful application of adhesive restorative materials is recommended (Composite, Compomer, GIC [glass ionomer cement]). For smaller occlusal cavities, Cavit (3M Espe, Seefeld, Germany) is indicated for short-term temporary restorations (1–2 weeks).

Care should be taken to ensure that the thickness of the temporary filling (especially cavit) is adequate (4–5 mm) and that cotton fibers do not penetrate the restoration.



26.4 Covering the root canal orifices

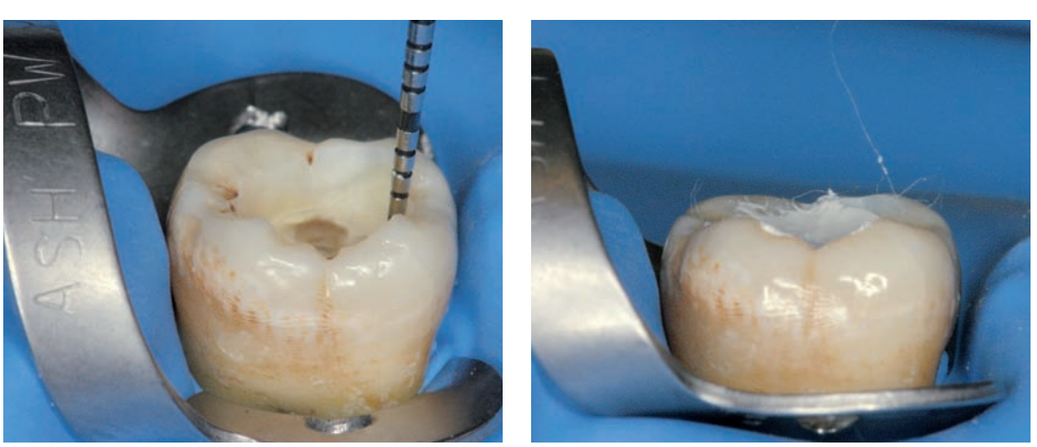
Following thorough drying of the root canals, and insertion of the dressing into the root canal, the root canal orifices are covered using small, individually prepared cotton or foam pellets.



26.5 Cavit

Left: With large access cavities, a layer of Cavit can be applied initially.

Middle and right: Cavit exhibits an excellent temporary seal, but is not strong enough to resist occlusal forces. It is indicated only for short-term restoration of small cavities or as a base layer in larger cavities, which are subsequently restored with an adhesive material that can resist the masticatory forces.



26.6 Cavit

Left: A minimal thickness of 3.5 mm of Cavit is necessary to ensure a bacteria-tight seal of the access cavity. The necessary space can be assessed by using a periodontal probe.

Right: Note the cotton fibers extending beyond the occlusal restoration; these represent a path for the penetration of oral microorganisms into the access cavity.

26.7 Cavit

Left: Tooth 47 immediately after root canal obturation and temporary sealing with Cavit.

Middle and right: On re-examination of the patient 2.5 years later, further carious destruction of the tooth was evident clinically and radiographically, as no definitive restoration had been performed in the intervening period.

26.8 Removal of the dressing

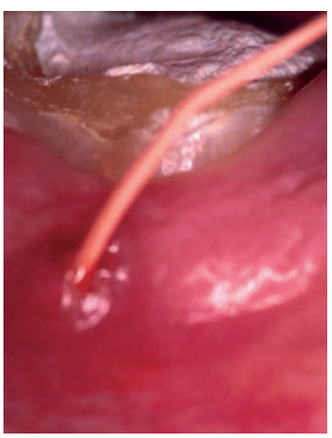
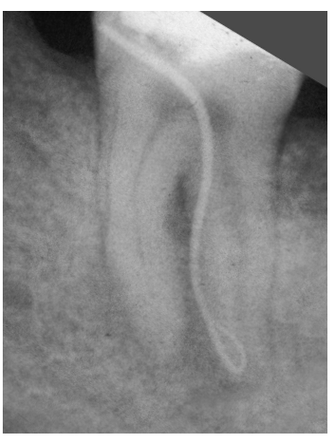
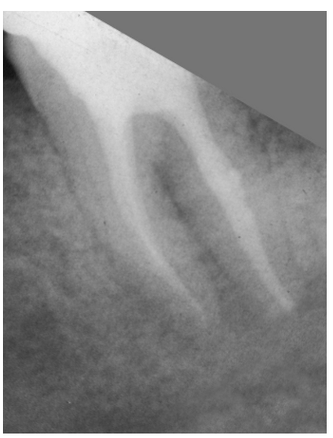
For complete removal of the temporary dressing, copious root canal irrigation and the use of ultrasonic systems and/or additional mechanical instrumentation are necessary.

26.9 Success of the disinfection procedure

Left: The tooth with a sinus tract on the buccal aspect.

Middle: The preoperative radiograph reveals large peri- and interradicular lesions.

Right: The 1-year follow-up radiograph shows complete osseous regeneration following intensive disinfection by the use of copious irrigation and intracanal dressings.

26.10 Success of the disinfection procedure

Left: The radiograph shows extensive periodontal and interradicular bone loss.

Right: This radiograph taken 8 months later shows almost complete osseous regeneration as a consequence of intensive disinfection through the use of copious irrigation and intracanal dressings.

Root Canal Filling

E

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27 Introduction

In endodontics, the root canal filling should not only provide an impermeable barrier to fluid and bacterial ingress, the material must also be biologically compatible following insertion into a chemo-mechanically instrumented, cleansed, and shaped root canal system (Schäfer, 2000).

Usually, it is necessary to use two different filling materials. To date, no single material has been shown to fulfill all the above mentioned prerequisites. The root canal filling material most commonly used worldwide is gutta-percha. Regardless of the clinical technique used to compact gutta-percha within the root canal, use of this material without simultaneous application of a root canal "sealer" will inevitably result in some inadequately obturated sections of the root canal (Tagger et al., 1994).

However, even today, most sealers cannot be relied on to maintain the treated root canal in a completely sealed state, because — and especially with larger paste volumes — almost all root canal sealers contract on setting, which can lead to less than satisfactory adaptation against the root canal wall. For this reason, at least 90% of the filling in every obturated root canal should be gutta-percha, because in contrast with most commercially available sealers, gutta-percha does not shrink as it hardens.

The primary purpose of a root canal sealer is to fill any voids left in the root canal due to incongruence between the shape of the root canal wall and that of the central filling material (gutta-percha) and to stabilize the volume (mass) of the filling. For this purpose, sealer pastes that remain soft are clearly not suitable. They will remain soluble and can be resorbed by any remaining vital soft tissue, which can lead to reinfection of the endodontium (Ørstavik et al., 1987).

Over the years, many setting sealers with different chemical compositions have been developed (Schäfer, 2000). Today, there is international consensus that sealers with medicinal additives should be avoided. Such sealers usually contain mixtures of paraformaldehyde or corticosteroids and therefore must be considered with regard to their biologic impact. The critical assessment of such preparations is based not only on their local effects but also on their potential systemic adverse effects.

Sealers containing paraformaldehyde (e.g., N2) release formaldehyde during and after the setting process. Such preparations are considered neurotoxic, cytotoxic, genotoxic and also have significant allergenic potential. The healing of existing periapical inflammation is inhibited by the use of these sealants (Tepel et al., 1994). On the other hand, corticosteroids elicit local immunosuppression via various biologic mechanisms. The use of corticosteroid-containing sealers (e.g., Endomethasone N) often leads to an uncontrolled local colonization of microorganisms, which further leads to enhancement of any pre-existing periapical inflammation (Tepel et al., 1994).

Today, the use of root canal filling pastes with paraformaldehyde and/or corticosteroid additives must be viewed as obsolete and stands in clear contradiction to the modern biologic basis and principles of endodontology.

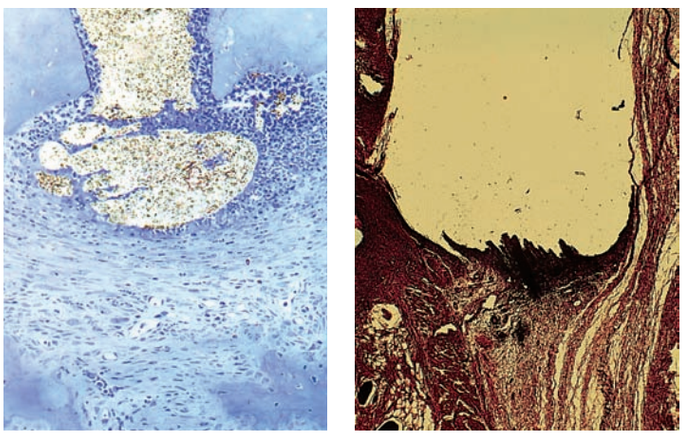
According to the quality guidelines of the European Association of Endodontology, all recommendations advise against the use of root canal sealers that contain paraformaldehyde or corticosteroids (European Society of Endodontology, 2006).

28 Root Canal Filling Pastes

Sealers containing *zinc oxide eugenol* set via the formation of a comparatively highly soluble zinc-eugenolate complex, which also has poor compressive strength. Free eugenol is cytotoxic, but with proper mixing it is bound to the eugenolate as well as the zinc oxide.

Eugenol can act as an allergen, causing contact urticaria or even an anaphylactic reaction (Grade, 1995). In patients with a known allergy to eugenol or Peruvian balsam, the use of these sealers is contraindicated. During the setting procedure, these compounds exhibit shrinkage of about 0.3–1%.

Due to a condensation reaction, *epoxy resin* AH 26 releases very little formaldehyde during its rapid setting process (Spangberg et al., 1993). For this reason, AH 26 has low cytotoxicity initially (Leonardo et al., 1999), and is virtually undetectable after several weeks. AH Plus (Dentsply International, PA, USA), the improved version of the AH 26 sealer, releases virtually no formaldehyde, due to an addition reaction. For this reason it exhibits improved biocompatibility in comparison with the original AH 26 (Rödig et al., 2005a). AH Plus is identical to 2Seal paste (VDW, Munich, Germany). Overall, sealers with an epoxy resin base have very good



28.1 Biocompatibility of root canal filling pastes/sealers

Left: Animal studies indicated that the epoxide resin 2Seal is associated with a good tissue reaction despite slight overfilling of the canal.

Right: Extensive undesirable tissue reaction following subcutaneous implantation of a sealer based on zinc oxide eugenol.

28.2 Root canal sealers based on epoxy resins

The original epoxide resin AH 26 (Dentsply, DeTrey, PA, USA) in the form of a powder-liquid preparation (left). The successor to AH 26, the paste-paste material AH Plus (Dentsply, DeTrey) (above right). Identical to AH Plus is 2Seal (VDW Antaeos, Munich, Germany), which is also a paste-paste material (below right).

physical characteristics with regard to viscosity, solubility, and radiopacity. AH Plus, in particular, is virtually insoluble (Schäfer and Zandbiglari, 2003). In general, these types of sealers have excellent sealing ability and good volume stability.

Sealers containing *calcium hydroxide* have very good biocompatibility (Heil, 1996); however, Sealapex (SybronEndo, CA, USA) has been demonstrated to have high solubility, which can lead to the development of significant marginal gaps in the root canal filling (Siqueira, 1999). Sealers based on *glass ionomer cement* are characterized as tissue-compatible and nonresorbable. One disadvantage of these preparations, however, is their comparatively high solubility.

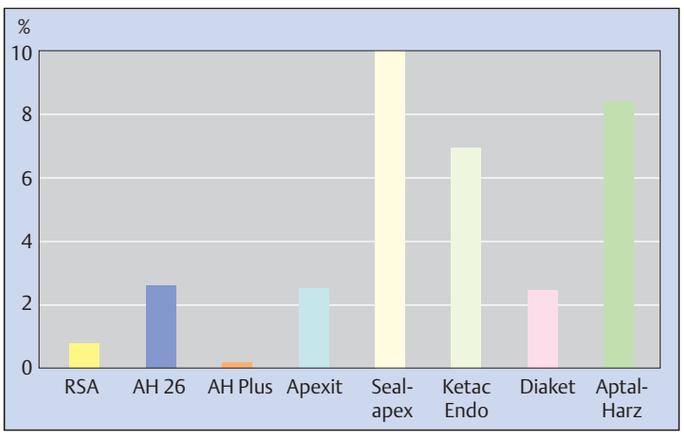
Diaket (ESPE, Seefeld, Germany) a *polyketone*, hardens in approximately 7 minutes, which is often too quick for a complex root canal filling procedure. On the other hand, the biocompatibility, sealing characteristics, and solubility of Diaket have been favorably reviewed (Matsumoto, 1989). Sealers based on guttapercha consist of a *gutta-percha* solution within an organic solvent (chloroform, eucalyptus oil, xylol). Because there is scientific evidence of a possible carcinogenic potential for both chloroform as well as xylol, the use of such root canal filling pastes in endodontic treatment is biologically incompatible.

One sealer based on *silicone*, RSA RoekoSeal Automix (Coltene Whaledent, OH, USA), exhibits good sealing characteristics (Wu, 2002) and tissue compatibility (Dammaschke et al., 2006), as well as low solubility.

Also interesting is GuttaFlow (Coltene Whaledent, OH, USA), a mixture of RSA RoekoSeal with 30–45 µm particles of gutta-percha. With a working time of 10 minutes, the setting process occurs via a chain reaction process within the polydimethylsiloxane. Because of its good flow characteristics, GuttaFlow provides excellent adaptation of the root canal filling to the canal walls (ElAyouti et al., 2005).

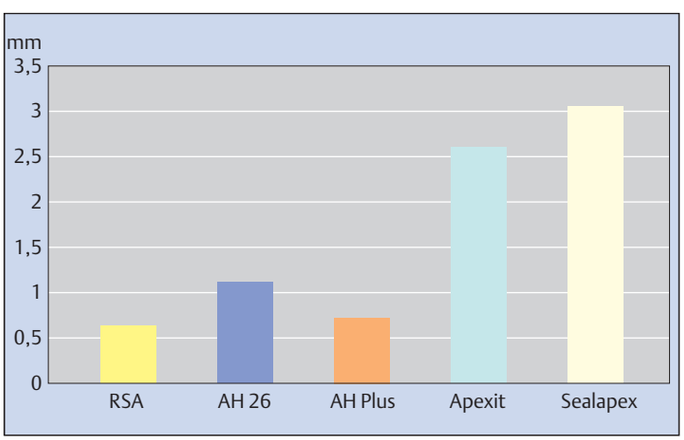
Newer filling materials are intended to provide better sealing of the root canal by means of an *adhesive technique*. Products such as Epiphany (RealSeal) from SybronEndo, CA, USA consist of a self-etching primer, a dual hardening sealer with a BisGMA base, as well as a polyester cone similar to gutta-percha (Rödig et al., 2005b).

The results of initial in vitro studies are promising (Teixeira et al., 2004; Shipper et al., 2005). There is a need for long-term prospective clinical studies to fully evaluate these acrylic-based filling materials.



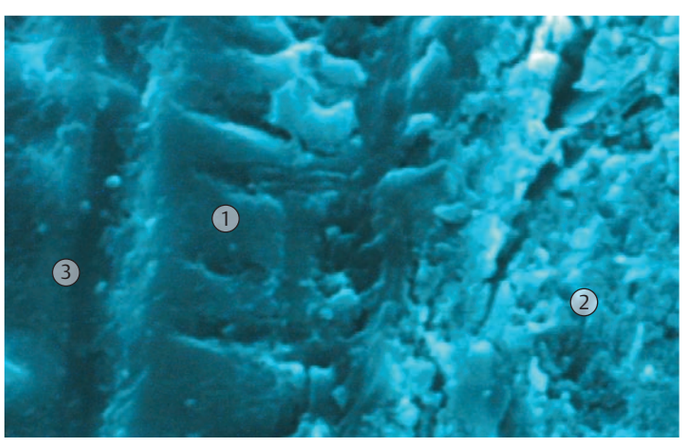
28.3 Solubility

Solubility values for various sealers following storage in water for 28 days. The sealers AH Plus and RSA RoekoSeal Automix exhibited very low solubility, while Sealapex and the zinc oxide eugenol based sealer Aptal-Harz (Speiko, Münster, Germany) exhibited extreme solubility.



28.4 Sealing characteristics

Apical dye penetration as a measure of the sealing characteristics of various sealers after filling of curved root canals using the lateral compaction technique. The silicone- and epoxide resin-based sealers provided excellent obturation, while sealers containing calcium hydroxide did not seal the root canals reliably and securely.



28.5 Adhesive root canal filling materials

This SEM image showing composite tags (1) of the sealer (RealSeal [2]) penetrating into the dentinal tubules (3). Both the primer and sealer achieve an adhesive bond with both dentin and the central filling material.

Left: RealSeal consists of BisGMA, UDMA, and difunctional methacrylate; the cone (Resilon) consists of polyester-based polycaprolactone, bioactive glass, and bismuth oxide, with a filler content of about 65%.

29 Lateral Compaction of Gutta-percha

Cold lateral compaction of gutta-percha continues to be the gold standard root canal filling technique and is the method most often used in routine endodontic practice (Slaus and Bottenberg, 2002). Because about 50% of gutta-percha points are thinner than the ISO norm (Schäfer and Göhring, 1993), the actual diameter of the master point should be checked with a measurement gauge (Fig. 29.1). Following mechanical root canal preparation using highly tapered instruments, a master point of corresponding taper should be used to simplify the root canal filling procedure and to increase the volume proportion of gutta-percha in the filling (Hembrough et al., 2002; Gordon et al., 2005).

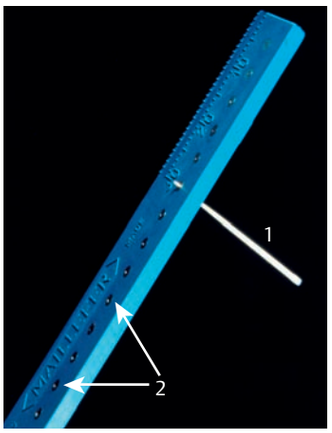
A precisely fitted master point should extend to the instrumented working length and exhibit slight friction in the apical portion of the canal; the latter can be clinically demonstrated by slight resistance (tug back) when removing the master point from the canal (Wesselink, 1995).

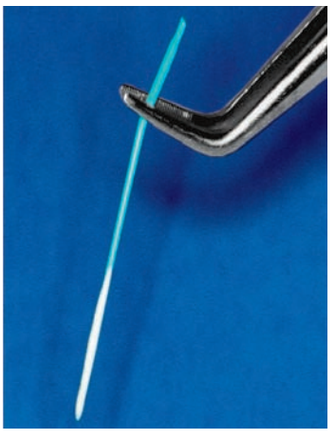
Finger spreaders instead of hand spreaders should be used for compaction, as this provides better sealing (Simons et al., 1991) and at the same time reduces the danger of vertical root fracture (Lertchirakarn et al., 1999).

29.1 Gutta-percha master point

Left: The holes (2) in the measurement gauge for gutta-percha points (1) are ISO standardized. If the tip of the gutta-percha point extrudes beyond the measurement gauge, this is an indication that the point is too thin and should be cut off using a scalpel. Following this, the tip diameter will correspond to the appropriate ISO size.

Right: A master point evenly coated with sealer.

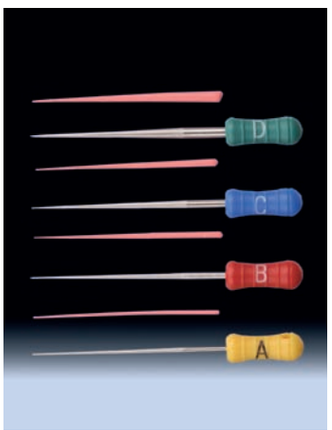


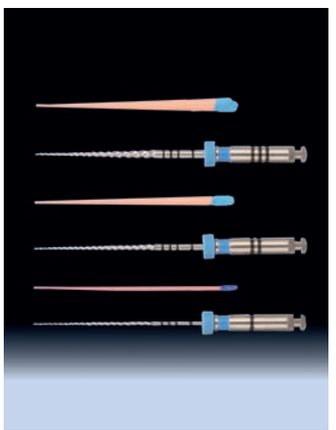


29.2 Highly tapered gutta-percha points

Left: The finger spreader should correspond to the taper of the selected master point.

Right: NiTi root canal instruments with 2%, 4%, and 6% taper displayed with gutta-percha points of identical taper.



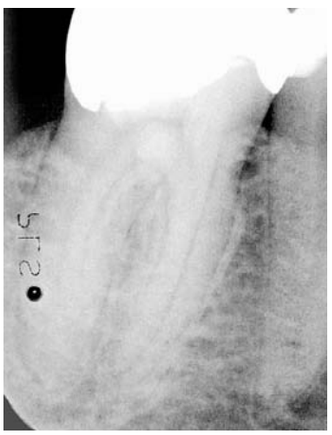


29.3 Root canal filling

Left: Diagnostic radiograph of tooth 46.

Middle: Working length determination radiograph.

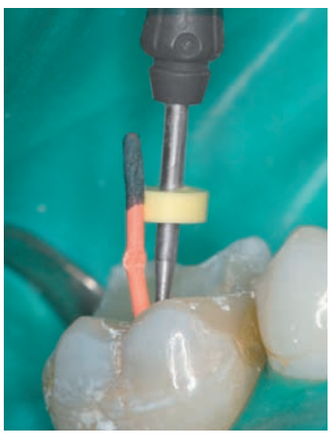
Right: Clinical view following preparation of the four root canals.



As a general rule, nickel-titanium (NiTi) finger spreaders are preferable to stainless-steel instruments because they produce less tension and can be inserted deeper into curved canals (Wilson and Baumgartner, 2003; Gharai et al., 2005). Only the *tip* of the master point is coated with a thin layer of sealer and then inserted slowly into the canal with a gentle pumping motion. The use of a Lentulo spiral is not generally recommended for root canal filling because of the increased danger of extrusion of sealer into the periapical tissues (Jeffrey, 1986; Hoen et al., 1988).

The accessory gutta-percha points should have the same taper as well as the same ISO size as the spreaders (Wesselink, 1995). The use of ISO-sized accessory points provides better sealing and compaction as compared with non-ISO-sized accessory points (Gound et al., 2001).

During the obturation procedure, only the tips of the first few accessory points should be lightly coated with sealer to improve the homogeneity of the compacted gutta-percha filling and to prevent any unnecessary increase in the amount of sealer within the root canal filling.



29.4 Initiation of compaction

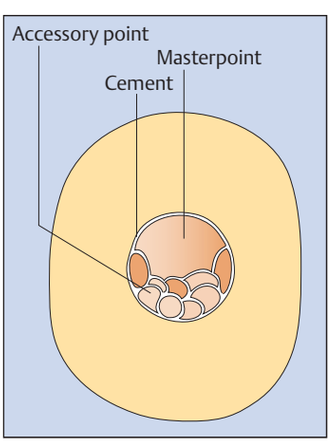
Left: The master point should have the same diameter as the last instrument used and it should be inserted inside the root canal to the full working length.

Right: A finger spreader with a silicone stopper is inserted to about 1–2 mm from the instrumentation endpoint and should be left within the canal for a short period to avoid any pull back of the preformed gutta-percha master point.

29.5 Compacting the gutta-percha

Left: The first accessory point should extend almost to the apical endpoint of the instrumented root canal. With each additional accessory point, the depth of insertion is reduced.

Right: Accessory points coated with a minimum amount of sealer are used to complete filling of the root canal.



29.6 Completion of lateral compaction

Left: Fully obturated root canal. The master point assumes the most prominent position within the root canal. The sealer simply fills the small remaining spaces.

Middle: The spare lengths of the gutta-percha points protruding from the coronal end of the root canals are removed using a heated instrument. Then the filling is compacted vertically from the coronal aspect, and finally the access cavity is well cleansed.

Right: Follow-up radiograph of the root canal filling.

Lateral compaction should be continued until the spreader extends only 3–4 mm into the root canal, without increasing the apically directed force. No attempt should be made to increase the number of accessory points by the application of excessive compaction force.

In an attempt to rework cold, semisolid gutta-percha with a spreader, clinicians often apply an excessively high force. Force between 1.5 kg and 7.2 kg can lead to root fracture (vertical fracture) (Pitts et al., 1983). Such fractures usually occur in the buccopalatal or lingual plane (Holcomb et al., 1987). In many instances, the initial lesion is only a slight crack in the root dentin, which develops into a complete vertical root fracture as a result of masticatory forces. Subsequent clinical symptoms point to the correct diagnosis (Tamse et al., 1999). The incidence of such root fractures is about 3.7% (Morfis, 1990).

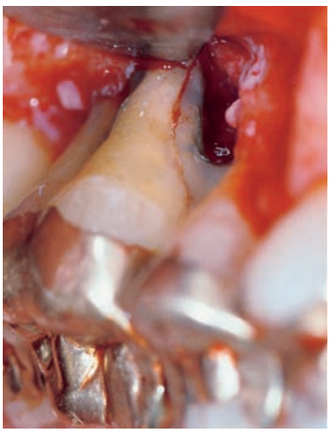
With clinically appropriate lateral compaction, even in curved root canals, the proportion of gutta-percha in contact with the root canal exceeds 90% (Gordon et al., 2005).

After completion of the root canal filling procedure, the gutta-percha points extruding from the root canal orifices are severed with a heated instrument (e.g., GuttaCut, VDW, Munich, Germany) below the dentinoenamel junction. Immediately afterward, the gutta-percha in the region of the root canal orifices is vertically compacted using a heated plugger or stopper to achieve the maximum possible compression. Finally, the endodontic access cavity is completely cleansed of any remnants of the filling materials because most such materials can lead to dentin discoloration.

29.7 Vertical root fracture

Left: Radiograph of an extensive root fracture of tooth 46.

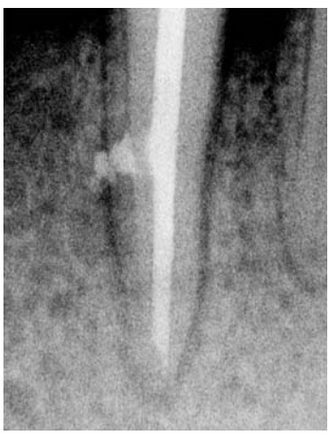
Right: Following surgical exposure of the palatal root of the endodontically treated tooth 26, the clinical diagnosis of vertical root fracture was confirmed.



29.8 Results of lateral compaction

Left: Even accessory/lateral canals can be at least partially filled by using the technique of lateral compaction.

Right: A dye penetration test on this transparent preparation reveals obvious staining of the root canal, indicating unsatisfactory apical sealing following incomplete lateral compaction.



Furthermore, before definitive coronal restoration, the floor of the pulp chamber should be sealed using an adhesive material in order to seal any accessory canals in the furcation area (Wesselink, 1995); about 80% of multirooted teeth (Dammaschke, 2004) have accessory canals in this region.

The prognosis for teeth treated endodontically with the lateral compaction technique is universally very good. One clinical study revealed that after 4–6 years the success rate was 93% in teeth without apical periodontitis, and for teeth with initial apical periodontitis the success rate was 67% (Friedman, 2003). Another study revealed that after 1 year the success rate was 87% in teeth without periapical radiolucency and 80% in teeth with a preoperative radiolucency (Peak, 2001).

30 Vertical Compaction of Warmed Gutta-percha

An article written over 40 years ago by Herbert Schilder, "Filling Root Canals in Three Dimensions," was the foundation stone for an endodontic treatment concept defining the universally recognized principles of modern endodontic therapy. According to Schilder (1967), lesions of endodontic origin possess a healing capacity of 100% minus X!

In this equation, the factor X is determined by instrumentation and cleansing, mechanical sterilization and three-dimensional filling of the root canal system. Numerous clinical and histologic studies have demonstrated the occurrence of ramifications, anastomoses, indentations, and the formation of deltas within the root canals (Hess, 1925). It follows that the rate of successful clinical outcomes can be increased by improved treatment techniques that lead to improved cleaning and sealing of the root canal system in its entire complexity.

A prerequisite for successful outcome following vertical compaction of warm gutta-percha is thorough cleaning and shaping of the root canal system. In this regard, Schilder defined specific mechanical and biologic criteria (Fig. 30.1; Schilder 1974).

The goal of the cleaning procedure is to ensure the root canal system is cleared of all organic components (necrotic soft tissue, other remnants, bacteria) as well as antigenic substances and toxins. Because these substances are the primary cause of periradicular lesions, their complete removal represents the very basis for successful treatment.

Shaping refers to the development of a logical cavity form to recieve a 3D hermetic filling of the entire root canal space Equally important, when properly accomplished, shaping facilitates cleaning. A properly shaped root canal prepared for the warm gutta-percha technique should have a continuously tapering funnel (mechanical objective 1), with the narrowest diameter in the region of the apical foramen and the widest at the coronal aspect (mechanical objective 2).

The preparation should be done in multiple planes and maintain the natural curvatures of the root canal being treated. It should flow along the *original anatomy* of the root canal (mechanical objective 3).

The original foramen should remain in its natural position, that is, it should not be transported along the root surface (mechanical objective 4). The apical opening should be kept as small as is practically possible, and it should not be widened unnecessarily beyond its original dimension (mechanical objective 5).

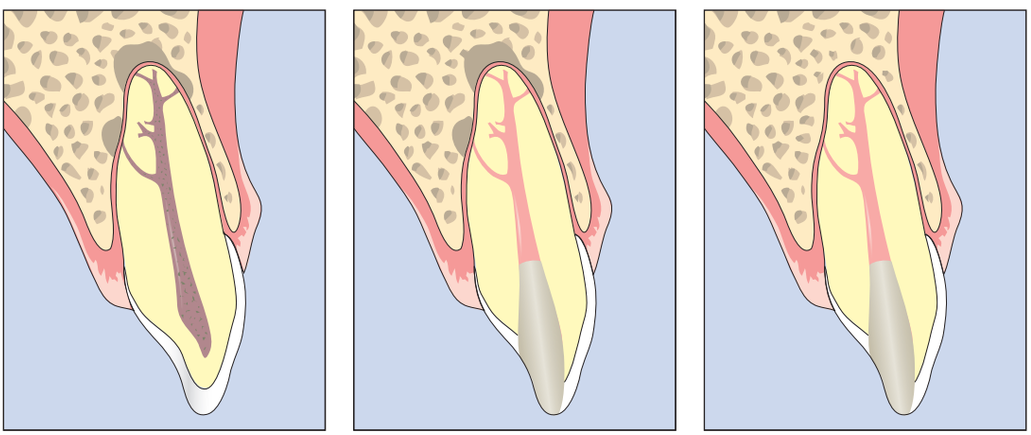
Vertical compaction of warm gutta-percha provides a very accurate duplication of the root canal system with a homogeneous mass of gutta-percha and a sealer film thickness measured in Angström units. With this technique, accessory canals are effectively filled in more than 40% of all cases. The goal is complete 3D obturation of the root canal system.

The goal stated above demands appropriate adaptation of a master cone, selection of appropriate pluggers, insertion into the root canal of the master cone that is coated minimally with the sealer, controlled heating of the gutta-percha with a heat carrier and then transfer of the heat waves from the coronal to apical end, along with forcing and compacting the gutta-percha into the root canal system.

Gutta-percha needs to be heated only 3–8 °C above normal body temperature to be able to mold it and successfully adapt it to any irregularities within the canal system. The vertical compaction technique is based on capturing the maximum cushion of softened gutta-percha with appropriate pluggers and moving the entrapped material toward the apex. During this clinical procedure, the plugger should never make direct contact with the root canal wall. The vertical force/pressure from the plugger also helps to prevent shrinkage of the material when it cools to body temperature.

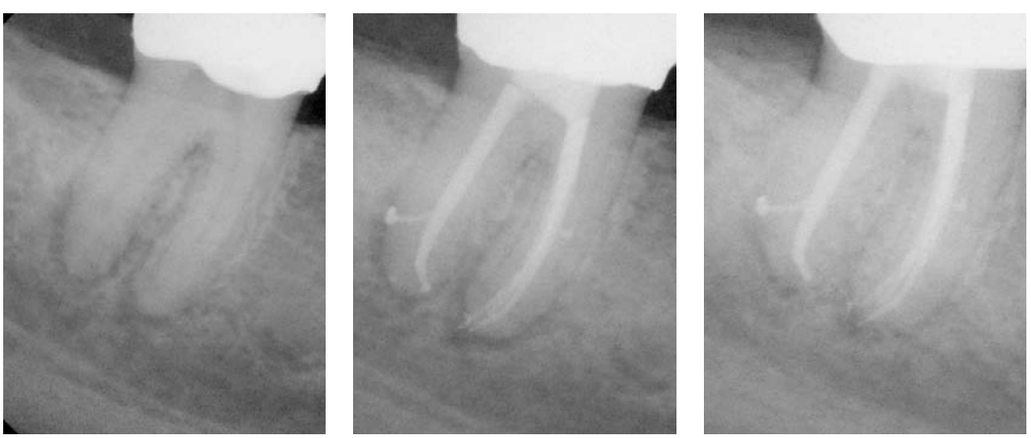
30.1 Schilder philosophy

Depending on the nature of bacterial infection, lesions of endodontic origin form symmetrically around the portals of exit (foramina) of the root canal system. The complete elimination of infection from within the root canal system, in combination with a 3D root canal filling, is a prerequisite for regeneration of the periodontium at the apex.



30.2 Predictability of the Schilder philosophy

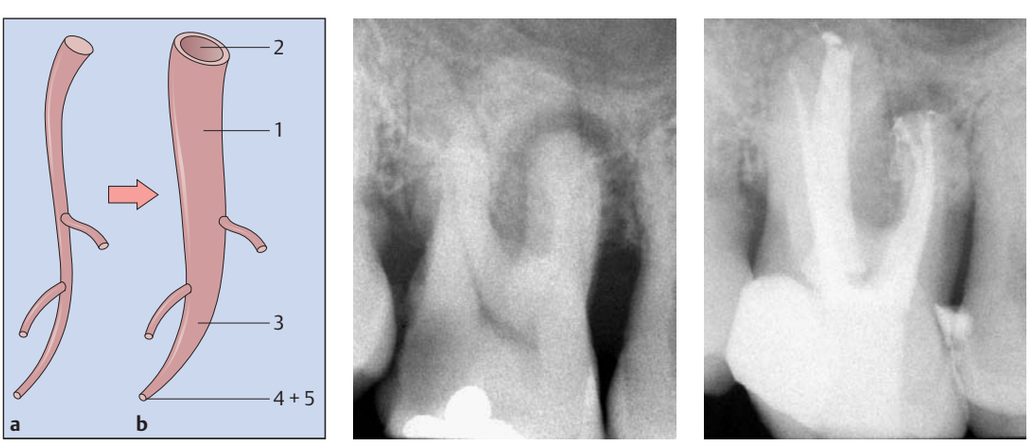
Following 3D shaping, cleaning, and filling of the root canal system, the healing capacity of the organism becomes manifest (left: preoperative radiograph, middle: immediately following root canal filling). Follow-up radiograph 3 months later (right) already demonstrating the healing capacity of the host tissue cells.



30.3 Schilder's five mechanical objectives

Left: **a** Root canal system with three foramina. **b** Diagrammatic depiction of the five mechanical objectives (see p. 229).

Middle and right: The primary goal of the Schilder concept is a 3D continuously tapered cavity that maintains the apical foramen in its original spatial position and size without unnecessary enlargement.

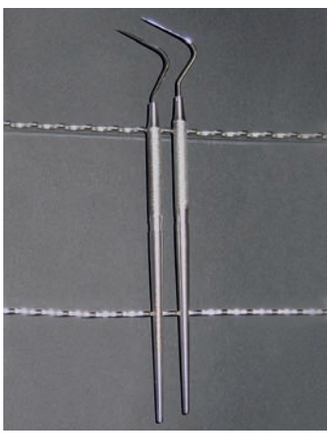


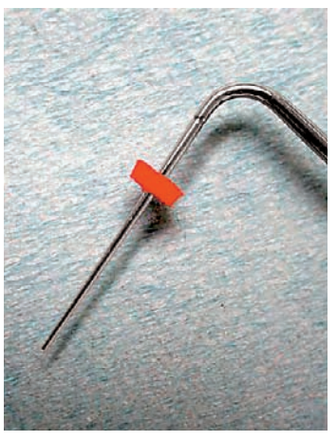
The vertical compaction of warm gutta-percha is comparable to the restoration of a Class 1 cavity with amalgam. It combines a simple clinical procedure with maximum efficiency in order to fill simple as well as anatomically complex 3D canals.

The authors favor the Touch'n Heat device (SybronEndo, CA, USA) because of its manageability and effectiveness in heating the gutta-percha to the desired temperature. The heat carrier is activated via a simple finger switch and quickly becomes red hot. When properly used, the gutta-percha is warmed to 45 °C, without leaving the stable β-phase.

Schilder pluggers are used to capture a maximum cushion of softened gutta-percha and to compact it vertically. In the smaller plugger size range, alternative NiTi pluggers are available, which can ensure compaction to the necessary depth, even in narrow or severely curved canal systems.

Endodontic treatment using a prepared tray of Schilder pluggers of the most often used sizes, as well as two NiTi pluggers (sizes 40 and 60) has proved to be effective. In most cases, the P-pluggers (P = posterior) are used because with their working length of approximately 23 mm their use is indicated in the majority of root canals.





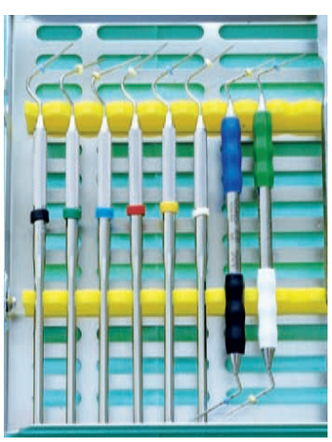
30.4 Heat transfer instrument

Heat carriers are similar to the spreaders used in the cold lateral compaction technique. Their purpose, however, is not to create space between individual gutta-percha points, but rather to distribute heat into the gutta-percha. They are available in sizes 0 and 00 (left) and are heated over a Bunsen burner (middle) until red hot.

Right: Close-up view of an electrically activated heat carrier.

30.5 Electrically activated heat transfer device

Electrical heating devices such as the Touch'n Heat (SybronEndo, CA, USA) or the System B (SybronEndo, Orange, CA, USA) permit precise control of the heat necessary to warm the gutta-percha and better control during the heating of removed gutta-percha mass. They also require less time to heat up in comparison to the classic heat carriers.



30.6 Pluggers

Endodontic pluggers resemble amalgam pluggers, except that the shaft is longer and thinner. They are fitted with markings at 5-mm intervals (middle) for simple length orientation. These are available as Schilder pluggers (Dentsply, Maillefer, Switzerland) (A = anterior) with a length of 30 mm and P-Plugger (P = posterior) with a length of 25 mm. The complete set consists of nine instruments with tip diameters of 0.40 mm (plugger size 8) up to 1.5 mm (plugger size 12) (left).

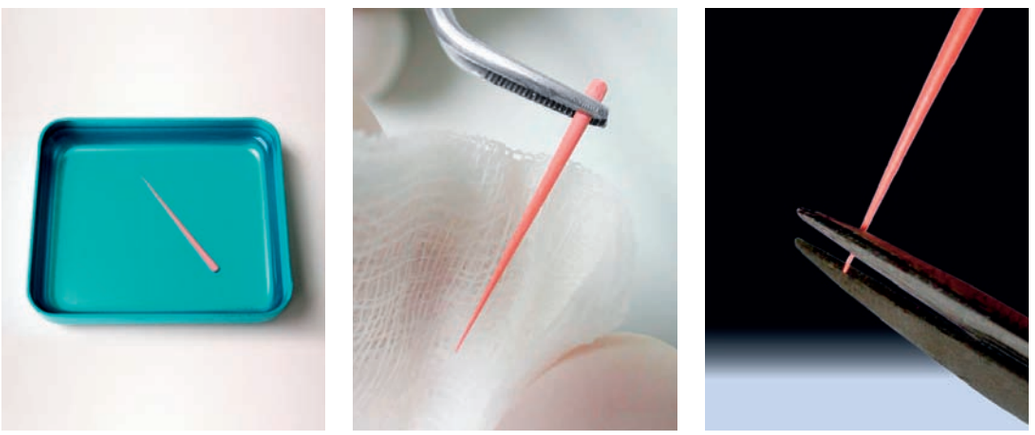
Right: Plugger tray and NiTi pluggers of the smallest sizes.

Preparation of the Gutta-percha Cone (Cone Fit)

The master gutta-percha cone must be selected very carefully. In most cases, a nonstandardized gutta-percha cone of “medium” or “fine medium” size is selected, whose taper is slightly less than the instrumented root canal. With exceptionally wide canals, one may also select a size “large” gutta-percha cone, which can then be thinned as necessary between two glass slabs and adapted individually to the taper of the canal.

The tip of the cone must be shortened so that its diameter is slightly larger than the last file that was used during instrumentation to the apical foramen. The adjusted gutta-percha cone should be fitted 0.5–1 mm short of the “radiographic terminus” of the canal, should exhibit “tug back”, and provide sufficient volume of gutta-percha for the subsequent compaction. This step in the endodontic process is checked radiographically and the appropriate height of the reference point is marked on the cone.

In ovoid canals an additional cone of “medium” size can be used in order to achieve the sufficient gutta-percha volume for optimum compaction.

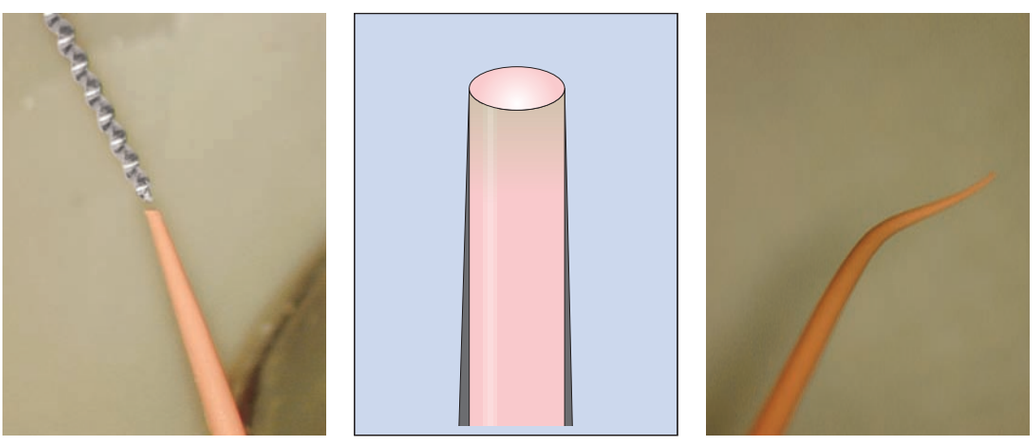


30.7 Preparing the master gutta-percha cone

Left: The gutta-percha cone is first disinfected in sodium hypochlorite solution and subsequently placed in an alcohol bath.

Middle: Before inserting the cone into the canal, the gutta-percha can be prebent using an alcohol-soaked gauze square.

Right: The tip of the gutta-percha cone is adapted to the desired diameter by trimming the tip with microscissors or a scalpel.

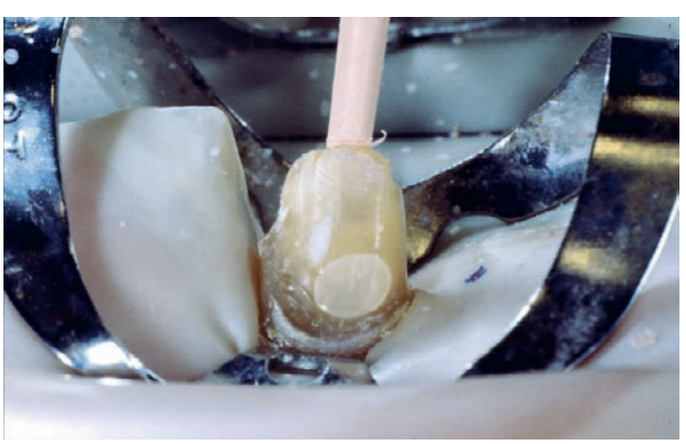


30.8 Cone fit I

Left: The correct dimension of the gutta-percha cone in the apical segment is checked against the master apical file.

Middle: The cone should only exhibit a tug back in the apical 2–3 mm, not over its entire length.

Right: A well-adapted cone will reflect the “flow” of the root canal system.



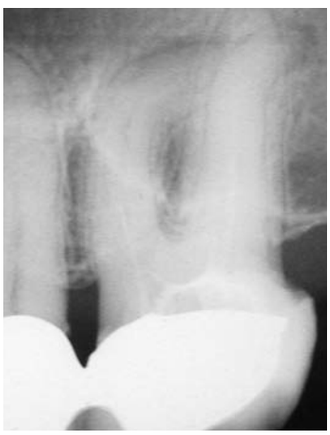
30.9 Cone fit II

An indentation is made on the inserted cone, corresponding to the level of the reference point on the tooth (cusp tip), to ensure correct positioning of the cone during cementation.

As soon as the gutta-percha has been warmed and vertically compacted, it is slowly forced apically into increasingly smaller sections of the canal. Similar to forcing a cork into a wine bottle, this leads to deformation of the cone and a very dense filling with excellent apical sealing. If the gutta-percha cone is not appropriately shortened, it will extrude beyond the apex.

The same will occur if the "tug back" of the gutta-percha cone occurs not in the apical region but more coronally in the root canal. In this case, a cone of less taper must be selected and shortened apically until a "tug back" at the apex is discernable.

If there is no tug back felt, or if during positioning of the cone, the tip is jolted, the root canal should be irrigated again and one or two recapitulations with appropriate files should be carried out in order to ensure that, in particular, the apical portion of the root canal has a smooth and continuously tapering shape as well as being patent.

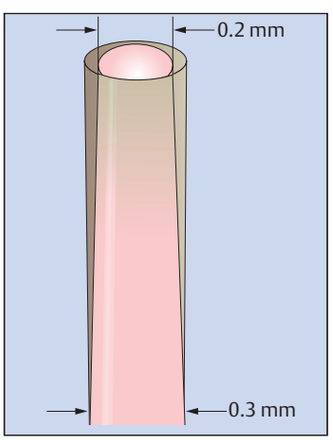


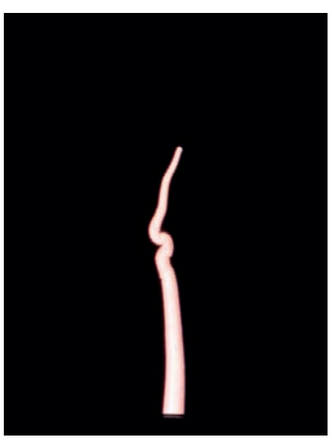
30.10 Vertical compaction of warm gutta-percha

Left: Preoperative radiograph.

Middle: The cone fit must be checked radiographically with regard to its vertical extension and taper.

Right: For the root canal filling procedure, the gutta-percha cone is made approximately 0.5–0.75 mm shorter than the working length, which permits optimum control in the apical ramifications of the root canal system during compaction.

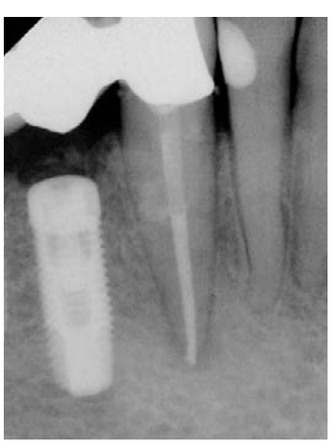




30.11 Incorrect cone fit

Left: The cone exhibits tug back not at the apical region but rather in the coronal portion of the root canal. A cone of this configuration will extend beyond the apical foramen during compaction and will not provide a 3D seal.

Right: A bent cone is an indicator that the five mechanical objectives of root canal preparation have not been fulfilled.



30.12 Overextended root canal filling

Error during instrumentation: inadequate taper as well as incorrect adaptation of the gutta-percha (improper cone fit) inevitably leads to a loss of apical control (left: preoperative radiograph; right: postoperative).

Selecting the Right Plugger

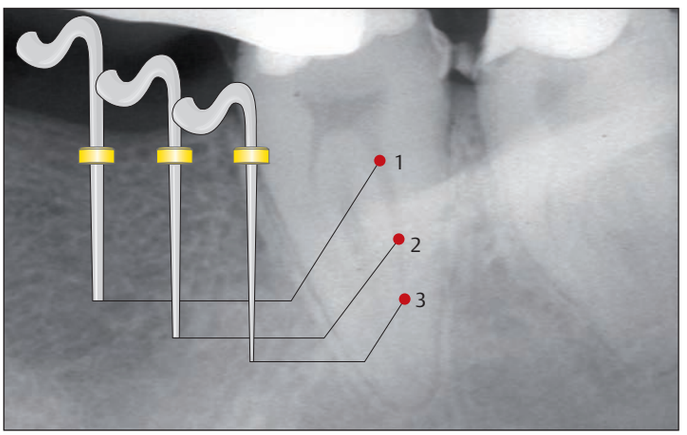
The pluggers must be adapted to the root canal, to determine the depth at which they can be utilized without contacting the root canal walls. The essence of the warm gutta-percha technique as described by Schilder (1967) is to capture the maximum cushion of softened gutta-percha and to compact it vertically. As a result of the tapered shape of the cavity, the gutta-percha can be simultaneously and efficiently compacted laterally.

To start with, a sufficiently large plugger (e.g., size 10.5) is inserted in the coronal third of the canal. A second, smaller plugger (e.g., size 9.5) is then selected, which extends into the middle third of the canal, and a rubber stop is utilized to control the depth of penetration and to prevent plugger contact with the canal wall. Finally a third, smaller plugger (e.g., size 8 or 8.5) is adapted to extend to about 5 mm from the foramen, and a rubber stop is utilized again for depth management.

The pluggers must never exert pressure against the canal walls because the resultant wedge effect could lead to root fracture.

30.13 Plugger selection and adaptation

A larger plugger is selected, which can work passively and efficiently in the coronal third of the root canal. A smaller plugger is selected for the middle third of the root canal. Finally, a still smaller plugger is selected, which can be inserted passively to a depth of 5–7 mm to the full working length.

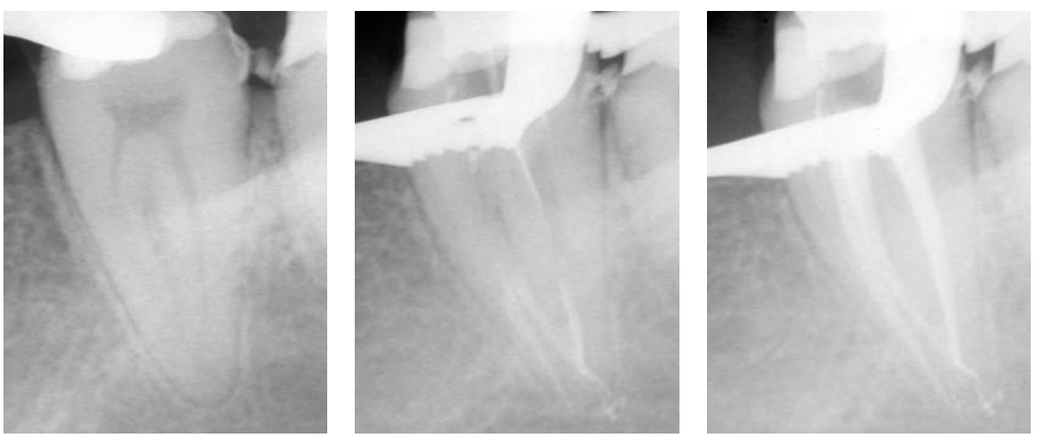


30.14 Clinical case

Left: Preoperative radiograph of a mandibular molar.

Middle: The down-pack image demonstrates how the plugger extends into the apical third of the root canal to ensure optimum 3D filling in this region.

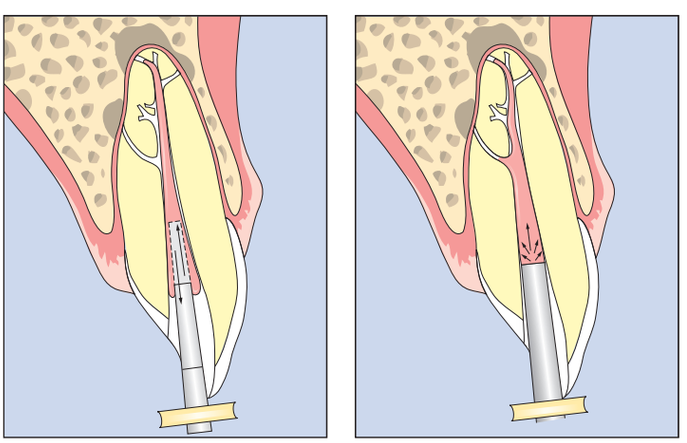
Right: The postoperative radiograph after the back-packing procedure shows a homogeneous root canal filling.



30.15 Plugger selection/ adaptation

Left: A plugger that is too small will penetrate into the thermoplastic gutta-percha mass but not compact it.

Right: To achieve the optimum hydraulic force, the plugger must engage the largest possible surface area of the thermoplastic gutta-percha. This means that its size must be proportional to the transverse section of each root canal segment in which it is engaged, without coming into contact with the root canal walls.



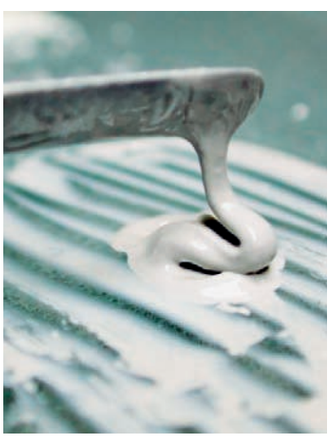
Cementing the Gutta-percha Cone

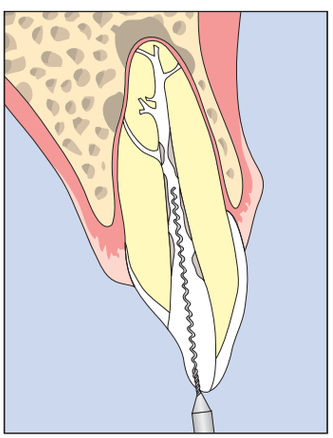
While the clinician is drying the canal with sterile paper points and the pressure-regulated Stropko irrigator (Sybron Endo, Orange, CA, USA), the cement is mixed in a powder–liquid ratio of 4.4:1. This ratio, in contrast to the recommendation of the manufacturer, provides a significantly denser consistency, which protects against porosity and reduces solubility, as well as improving the hydrodynamic characteristics of the cement. Because of its excellent flow characteristics, biocompatibility, rapid setting time, and prostaglandin inhibition, the Kerr Pulp Canal Sealer is the cement of choice for the warm gutta-percha technique (Ruddle, "Pathways of the Pulp," 1994).

Leakage through and around the cement can be minimized through a minimal layer thickness (Casanova, 1975). Warm gutta-percha fillings have only a microfilm of cement, which have a thickness between 3.62 µm and 9.36 µm (Nafafinejad, 1985). The coronal two-thirds of the root canal are filled with a minimum of cement by means of a Lentulo spiral hand instrument. A light layer of the cement is applied to the apical third of the gutta-percha cone and then slowly and without pressure positioned within the root canal. A radiograph should be taken to ensure the correct positioning of the gutta-percha cone.

30.16 Drying the canal

Ergonomic set-up for of the dental assistant in the 12 o'clock position (right). Using the Stropko irrigator with pressure reduction, and with the use of sterile paper points (left), which correspond to the taper of the root canal, the canal system is dried and the working length checked again.





30.17 Coating the canal walls with cement

Left: When mixed to proper consistency, it should be possible to lift the cement from the glass slab with a spatula, to a height of at least 2 cm.

Middle: The coronal and middle thirds of the root are coated with a minimal amount of cement using a hand Lentulo spiral.

Right: The gutta-percha cone is lightly coated with cement only in its apical third.

30.18 Cementing the gutta-percha cone

Left: Preoperative radiograph of a premolar.

Right: After coating the canal surface with cement, the cone is inserted to its proper position without applying pressure. This step can be checked radiographically. The radiograph of the "cemented" cone may demonstrate porosities of the cement layer in the coronal two-thirds of the root canal.

Down-packing

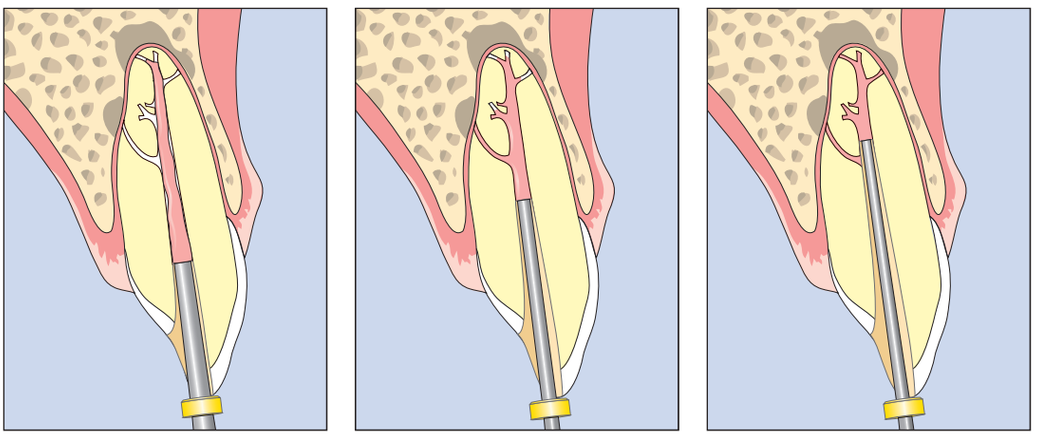
The portion of the gutta-percha cone that extends into the pulp chamber is softened and shortened using the heat carrier. Using the largest of the selected pluggers, the gutta-percha is compacted in the coronal part of the root canal. The goal is to engage the largest possible surface of softened gutta-percha and force it in the apical direction. Meanwhile, the plugger is moved circumferentially in short definitive movements within the gutta-percha.

The heat carrier is warmed red hot, extended 3–4 mm into the gutta-percha, then immediately removed. At the same time, a small portion of the gutta-percha should be removed. The thermoplastic gutta-percha can now be compacted vertically. The cavity walls should be maintained free of gutta-percha residues. Increasingly smaller pluggers should be used to prevent contact with the root canal walls during compaction. The rhythmic alternation between heating and plugging is continued to a depth of 5–7 mm of the working length.

According to the thermophysical characteristics of gutta-percha (Goodman et al., 1981; Schilder et al., 1985), the heat from the heat carrier extends about 4 mm deeper than the probe tip, ensuring adequate and controlled softening of the apical gutta-percha and achieving filling of the small lateral canals or of the apical delta (Yared and Dagher, 1995).

30.19 Down-packing

With ovoid canals, an additional gutta-percha cone or gutta-percha from the Obtura pistol can be placed into the canal in order to provide more mass for optimum compaction. The surface of the plugger is coated with cement powder to avoid sticking to the gutta-percha cone. The compaction proceeds in subsequent stages until the desired depth is achieved: compaction in the coronal (left), middle (middle), and apical (right) thirds.

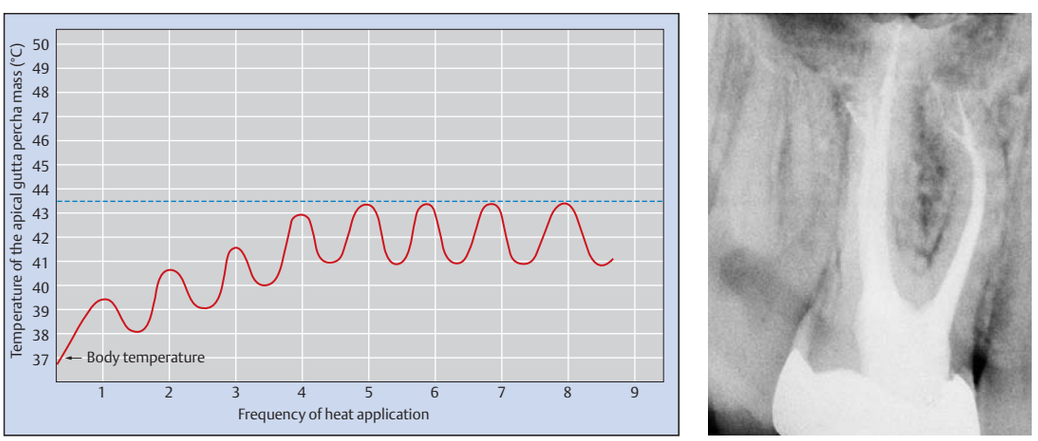


30.20 Hydraulic forces

As soon as the cycle of compaction begins, significant hydrostatic force is created within the closed space of the root canal because of the tapered cavity shape and the vertical force on the thermoplastic gutta-percha. Radiographs (left and right) demonstrate that all lateral canals from coronal to apical are filled as a result. At the "point of deepest pack," the thinnest plugger should be held under pressure for about 10 seconds to prevent shrinking of the gutta-percha as it cools.

30.21 Thermal profile

The temperature of the apical gutta-percha mass increases to a few degrees above body temperature. This temperature elevation does not, however, lead to any alteration of the crystalline structure (β phase), but only to minimal shrinkage during the cooling process and to excellent apical sealing. The back-pack procedure fills the coronal space and seals without voids (right).



Back-packing

Following the down pack procedure, the root canal in its middle and coronal thirds is successively filled from apical toward coronal. For this procedure, 3–4 mm sized gutta-percha segments of varying diameters are inserted into the canal, warmed, then compacted using pluggers.

As an alternative, the thermoplastic gutta-percha can be directly injected into the root canal and compacted using the Obtura-II system (SybronEndo, Orange, CA, USA). For this procedure, the warmed, prebent cannula of the Obtura pistol is introduced into the canal until it comes into contact with the already compacted gutta-percha within the canal, then a small portion of the thermoplastic mass is applied. This method of warming the gutta-percha mass leads to a cohesive and homogeneous gutta-percha root canal filling during the back-packing procedure.

In molars, the floor of the pulp chamber is also coated with thermoplastic gutta-percha and sealer to ensure that furcation canals in this region are also sealed. If a post and core (intraradicular anchored) restoration of the tooth is planned, the back-pack is only carried out to the necessary level.

30.22 Pistol system for the back-pack procedure

An elegant and time-saving alternative to the back-pack procedure is offered by the thermoplasticized gutta-percha of the Obtura-II system (Obtura Spartan, Earth City, Missouri, USA). In this system, prefabricated pellets are used.

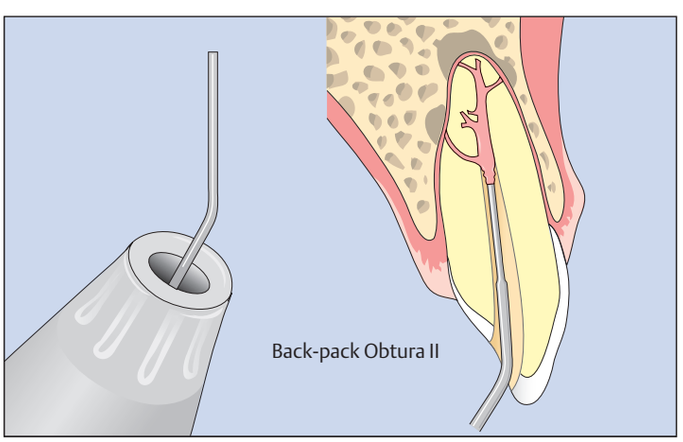
Left: Precut gutta-percha segments of varying diameters.

30.23 Error during the back-pack procedure

Gutta-percha remnants left on the canal walls can lead to voids during the back-pack procedure. Insufficient heating of the apical gutta-percha or the application of an excessive amount of gutta-percha from the Obtura pistol may also result in macroporosities in the filling.

The radiograph, left, reveals porosities in the back-pack root canal.

Middle and right: 3D filled root canal system following the back-pack procedure.



30.24 Original back-pack

The back-pack technique using the Obtura system requires a certain amount of experience to make certain that the application of successive gutta-percha segments creates a porosity-free adaption within the down-pack procedure.

Left: Previously clinicians would utilize small-, medium-, or large-sized pieces of precut gutta-percha, which were then warmed and compacted using hand pluggers.

Overfilling Versus Overextension

When a clinician aims for a 3D obturation of the root canal system, from time to time the result is the so-called Schilder puffs: slight overfilling with sealer, which lead to characteristic apical extrusion of the sealer. Histologic studies as well as thousands of clinical cases have demonstrated that this effect has no negative impact on the success of healing (Forgione, 1986).

It is necessary to differentiate between overfilling and underfilling, and overextension and underextension. Over- and underextension refer solely to the vertical dimension of the root canal filling, beyond or short of the root apex. Underfilling refers to a tooth whose root canal system has been inadequately obturated in any dimension. An overfilled canal is one that has been filled in three dimensions with a surplus of material (gutta-percha and/or sealer) extruding beyond the root apex. However, numerous cases of failure of vertical overextension with underfilled root canals have been encountered. In this case, the apical canal space is not securely filled or sealed, (e.g., by the single cone technique). These root canal fillings result in failure primarily because of insufficient shaping and cleaning of the root canal system, gross over-instrumentation and transportation of tissue and/or bacterial debris beyond the foramen, through residual infection, as well as leakage from the three-dimensionally underfilled canal system (West, 1975).

30.25 Schilder puffs

Left: The radiographic view of the initial situation reveals an underfilled root canal system.

Right: Following retreatment and detection of an additional root canal, the new root canal filling was performed using vertical compaction of warm gutta-percha. The radiograph reveals the so-called Schilder puffs, which indicate that the root canal system has been filled three-dimensionally (i.e., densely packed throughout and accessory and other canals have been filled too).

30.26 Overfilling

Left: Preoperatively, the premolar exhibited a large lesion on the distal lateral root surface.

Middle: Following retreatment on the distal aspect three large Schilder puffs are seen, which some describe as overfilling of the root canal. With 3D shaping and a three-dimensionally filled root canal system, however, this is irrelevant.

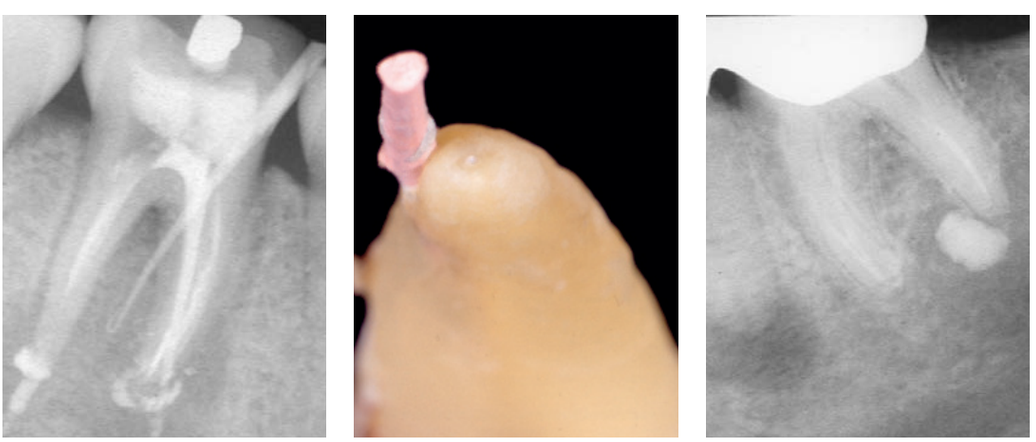
Right: The osseous regeneration of the lesion of endodontic origin proceeded independently and led to complete recovery.

30.27 Vertically overextended, three-dimensionally underfilled canal system

Left and middle: In contrast to the previous case, the massive overextension with gutta-percha and/or sealer seen here is contraindicated.

Middle: Apical view of the extracted tooth showing that the gutta-percha cone extended several millimeters beyond the root, not sealing the apical foramen.

Right: Massive extrusion in an otherwise underfilled canal system led to persisting postoperative complications. Disturbance of the healing process is inevitable in such a situation.



Discussion of the Schilder Technique

Some authors have proposed that the Schilder technique leads to uncontrolled overfilling, thermal damage to the periodontium, fissure formation resulting from the shrinkage of cooling, elevated risk of root fracture, or excessive instrumentation for the use of the plugger. Moreover, there is little evidence of clinical superiority compared with the cold lateral compaction technique.

As long as a clinician adheres meticulously to the Schilder protocol, the technique will lead to 3D, very well-adapted root canal fillings with excellent apical conformation (Wu et al., 2001). The gutta-percha is warmed to only slightly above normal body temperature, which compensates for possible shrinkage by apical pressure applied via the plugger (Schilder et al., 1985). Thermal tissue damage is of no consequence (Sweatman et al., 2001). The wedge effect on the root is significantly lower than with the cold lateral compaction technique (Blum et al., 1998), and randomized clinical studies have shown superiority compared with the cold lateral compaction technique (Farzaneh et al., 2004).

30.28 Coronal enlargement

Appropriate shaping presents a tapered cavity design for each individual tooth root (left: preoperative; right: postoperative). Coronal overenlargement should not be part of the treatment protocol, and could lead to unnecessary weakening of the tooth root.

30.29 Apical management

Left: Heavily calcified canal system with severe curvature.

Middle and right: The Schilder technique provides excellent apical management, with simultaneously optimal hydraulics.

30.30 Long-term success

Randomized clinical studies support the predictability of long-term success using the Schilder technique, as depicted here in a case with preoperative blockage of the root canal system (left), radiographic follow-up immediately after root canal filling (middle) and at 8-year follow-up (right).

31 System B/Obtura

The continuous wave of compaction technique was developed by Dr Stephen Buchanan in 1987 to simplify the warmed gutta-percha down-packing technique. With the warm vertical compaction technique, which involves three to four warming and compaction cycles, the application of heat during down-packing is interrupted three to four times. In contrast, the continuous wave technique of down-packing permits a single, regular movement of the material with continuous heating. The continuous wave process softens the gutta-percha mass mainly in a lateral direction and also in the coronal parts; it is therefore also possible to obturate lateral canals in the coronal area (Buchanan, 1994, 2005).

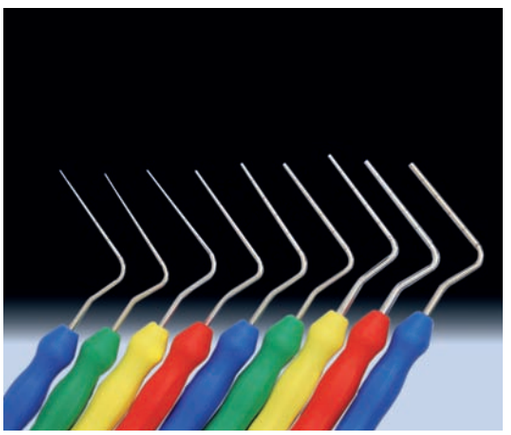
The System B heat source comes with continuous wave heat pluggers of various tapers, in accordance with the nonstandardized gutta-percha points. Hence most of the hand pluggers and the heat carrier are substituted with a single instrument during down-packing.

The backfilling is ideally performed with warmed gutta-percha (e.g., from the Obtura-III gun), which in contrast to the classical backfilling method, offers significant time saving. The Elements Obturation Unit is a recent development in which the System B heat carrier and the gutta-percha gun are combined into a single device.

31.1 The sealer

Left: The ideal sealer for use with the vertical compaction technique is Sybron Pulp Canal Sealer EWT (extended working time).

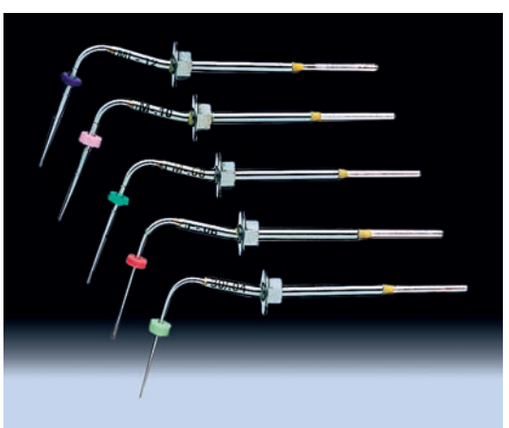
Right: Set of nine Schilder pluggers, sizes 8–12 in half sizes. These are commercially available for use in both anterior and posterior teeth.



31.2 Continuous wave heat pluggers

Left: The electric continuous wave heat pluggers are available in sizes (tip diameter/taper) 30/.04, 40/.06 (fine), 50/.08 (fine-medium), 60/.10 (medium), and 70/.12 (medium-large).

Right: System B permits temperature control; tapered tips are used for the continuous wave obturation technique.



31.3 Gutta-percha gun

Left: The backfilling technique is simplified with the use of a gutta-percha gun, Obtura II or Obtura III.

Right: The Elements Obturation Unit combines the continuous wave heat carrier and gutta-percha gun into one unit.

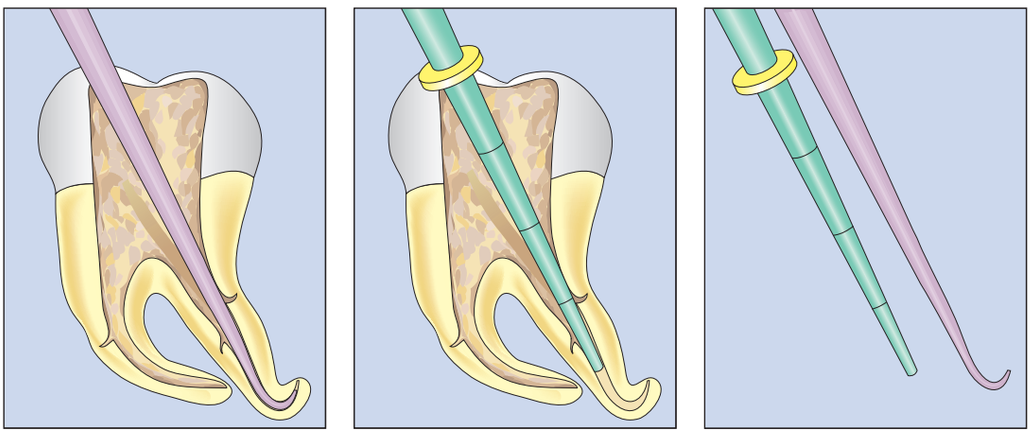
Preparation

The cone fit is determined in a process similar to the warm vertical compaction technique. The master cone is fitted to the entire working length and shortened by 0.5 mm before cementation. The continuous wave obturation heat plugger is selected to correspond with the taper of the master cone.

The continuous wave heat pluggers are characterized by two parameters. The first is the size of the nonstandardized gutta-percha points (extra-fine, fine, fine-medium, medium, and medium-large), and the other is the taper of the completed canal preparation (.04, .06, .08, .10, and .12).

The selected continuous wave heat plugger is pushed into the canal until it binds with the dentinal walls. The most apical "binding point" is marked with a rubber stopper and serves as a reference point during obturation.

By careful maneuvering within the canal, smaller continuous wave heat pluggers can be adapted to the root canal anatomy; larger ones should be carefully prebent to adapt to the curvature of the canal. The hand pluggers for down-pack as well as for back-fill compaction should be adapted before initiating the definitive obturation.

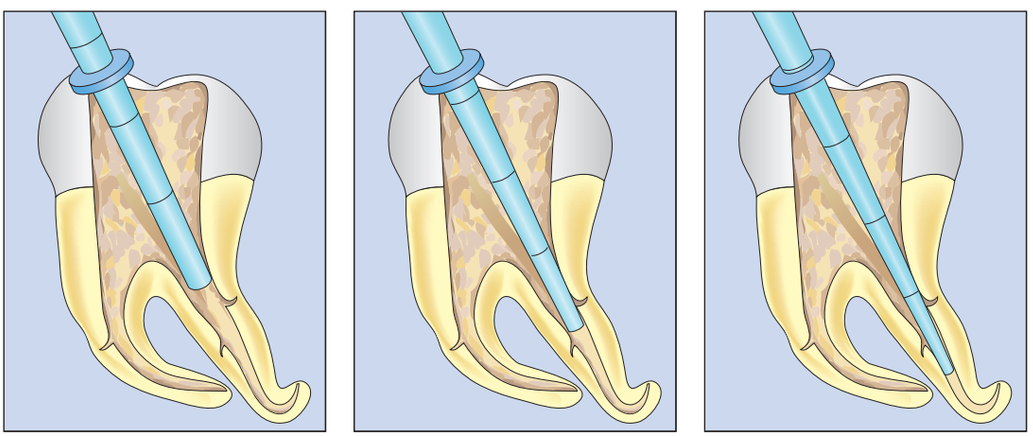


31.4 Selecting the master cone

Left: The master cone should extend to the full length, "bind" in the last 1 mm of the canal, and then be shortened by 0.5 mm.

Middle: The choice of the continuous wave heat plugger is determined by the taper of the master cone.

Right: Adapted master cone and continuous wave heat plugger; ideally, the plugger should reach a point 4–6 mm short of the full working length.

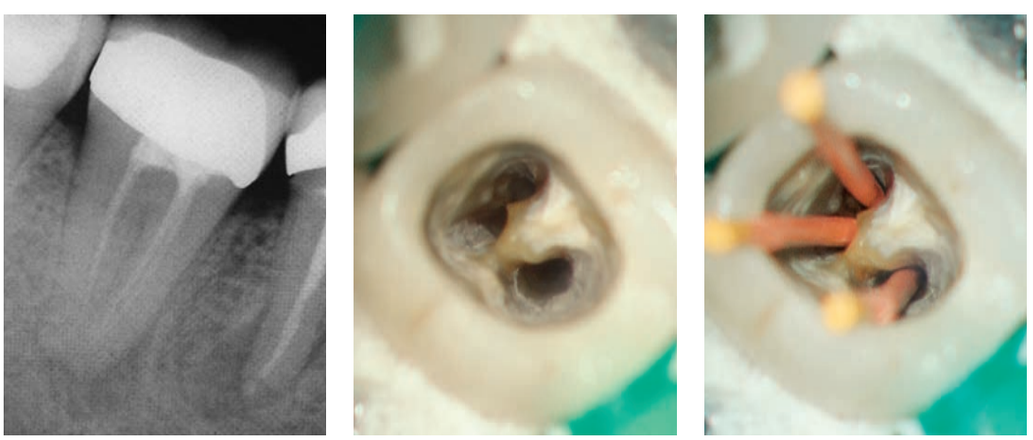


31.5 Hand plugger selection. The CW plugger must be adapted, and there should be a choice of at least three hand pluggers

Left: The first plugger should be inserted only a few millimeters into the canal without touching the dentinal walls. If the markings on the instrument are not satisfactory guides, rubber stoppers should be used.

Middle: The second plugger should extend to the middle of the canal, without touching the dentinal walls.

Right: The third plugger should extend into the apical section of the canal, 4–6 mm short of the full working length, again without contacting the dentinal walls.



31.6 Clinical example

Left: Radiograph showing a mandibular second molar root canal system with complex configuration.

Middle: Occlusal view of the pulp chamber following complete instrumentation.

Right: Fitting of the cone must be carried out extremely carefully in this case because of the complicated root canal anatomy and the fused canals.

Down-packing

After inserting the master cone with sealer (ideally Pulp Canal Sealer EWT) the cone is seared off at the canal orifice level and vertically compacted with the preselected hand plugger. For this procedure, the System B should be set, in general, at approximately 200°C. With the use of a size .04 or .06 plugger, the temperature can be maintained at 185°C, with a size .10 plugger at 220°C and with a size .12 plugger at 240°C (Buchanan, 2005). The power regulator is set at 10 and the "touch" function activated.

When using the Elements Unit, the high-heat down-packing mode can be activated independent of the plugger size.

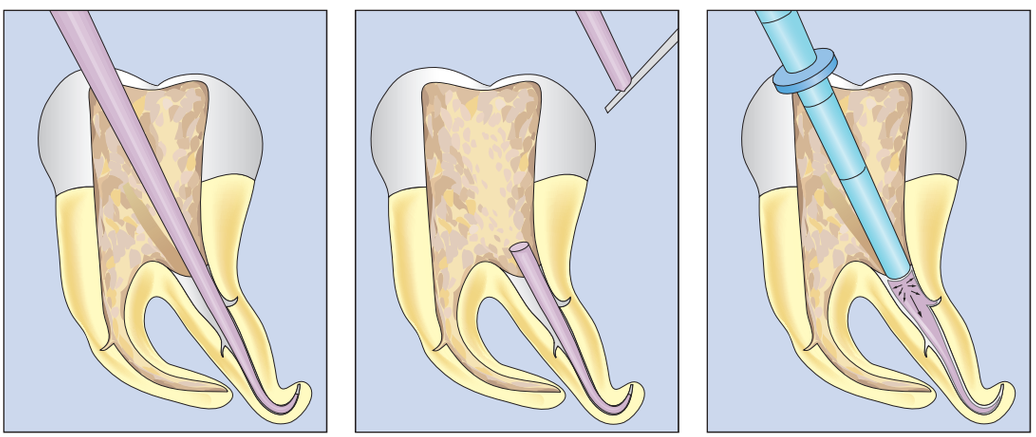
The continuous wave heat plugger is then brought into contact with the gutta-percha and activated and guided in a continuous movement through it. Shortly before reaching the binding point, the plugger is inactivated and additional apical pressure is applied. Then the plugger is inserted further into the gutta-percha to just coronal to the binding point. Pressure is then applied for an additional 10 seconds to compensate for shrinkage. After the apical compaction has been completed, the continuous wave heat plugger is activated for 1 second; following an additional 1-second pause, the plugger is removed with the surplus gutta-percha. The down-pack is then compacted using the preselected hand plugger.

31.7 Step I

Left: The master cone should "bind" the canal walls in the final apical 1 mm following adaptation to full working length, be shortened by 0.5 mm, and then be inserted with sealer into the canal.

Middle: The master cone is then seared off at the canal orifice with the activated continuous wave heat plugger.

Right: The warmed gutta-percha mass is then compacted using the preselected hand plugger.

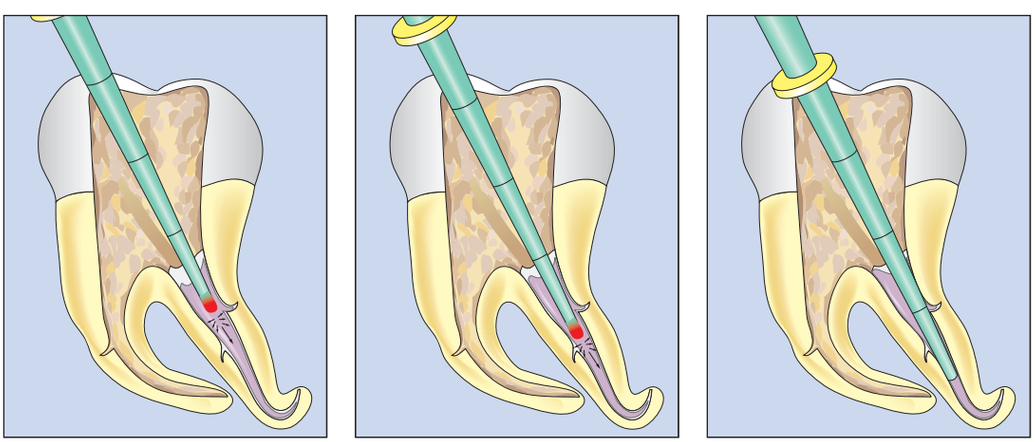


31.8 Step II

Left: The activated continuous wave heat plugger begins its journey through the cemented gutta-percha point.

Middle: The continuous wave heat plugger is kept activated up to 3–4 mm of the binding point.

Right: The continuous wave heat plugger is inactivated and moved further apically, stopping shortly before the binding point. Apical pressure is maintained for 10 seconds.

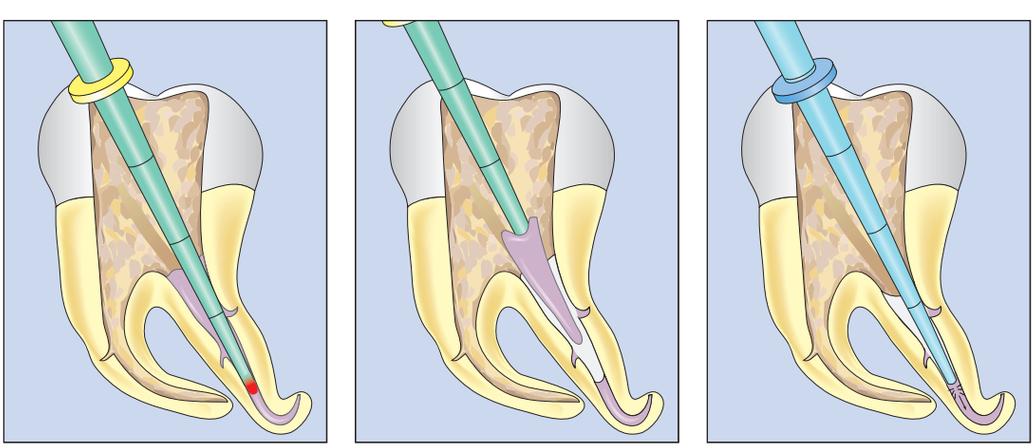


31.9 Step III

Left: Once the apical compaction is completed, heat is reapplied for 1 second.

Middle: The plugger with the attached gutta-percha is removed.

Right: The down-pack is then compacted using the preselected hand plugger.

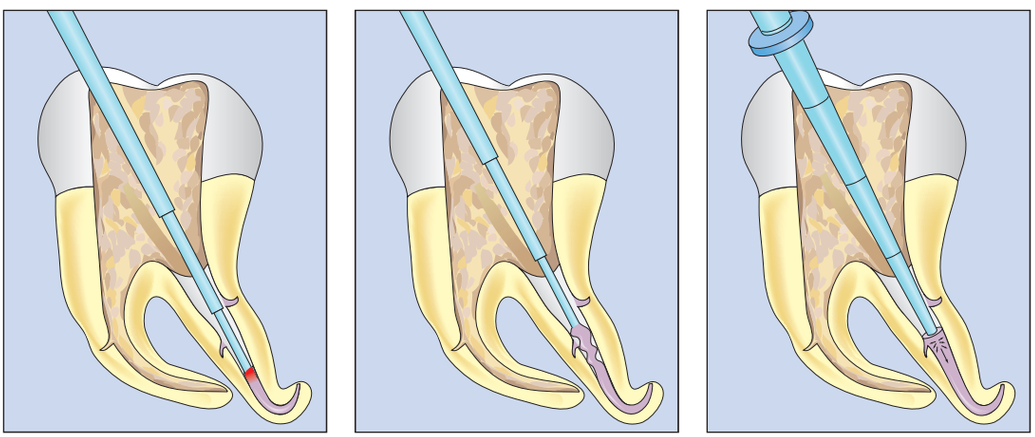


Back-packing

The back-packing procedure is identical to the warm vertical compaction technique described by Schilder, as well as the continuous wave technique of Buchanan. After completion of down-packing, this phase of obturation should be radiographically confirmed before filling the middle and coronal segments of the canal.

Ideally, a gutta-percha gun should be used for the back-packing procedure (e.g., the Obtura III gun or the gutta-percha extruder of the Elements Unit), both adjusted to a temperature of 200°C. The diameter of the sterling silver needle of the gutta-percha gun/extruder should be 20 G for "wide" canals, 23 G for "normal" canals, and 25 G for "narrow" canals.

Following introduction of the heated tip to the level of the down-pack, the surface of the gutta-percha is warmed for about 5 seconds and an improved seal is achieved. A small amount of gutta-percha is then inserted into the canal and compacted using the preselected plugger until the gutta-percha mass has cooled. This can be repeated up to the level of the canal orifices or stopped where practical to provide appropriate space for a post.

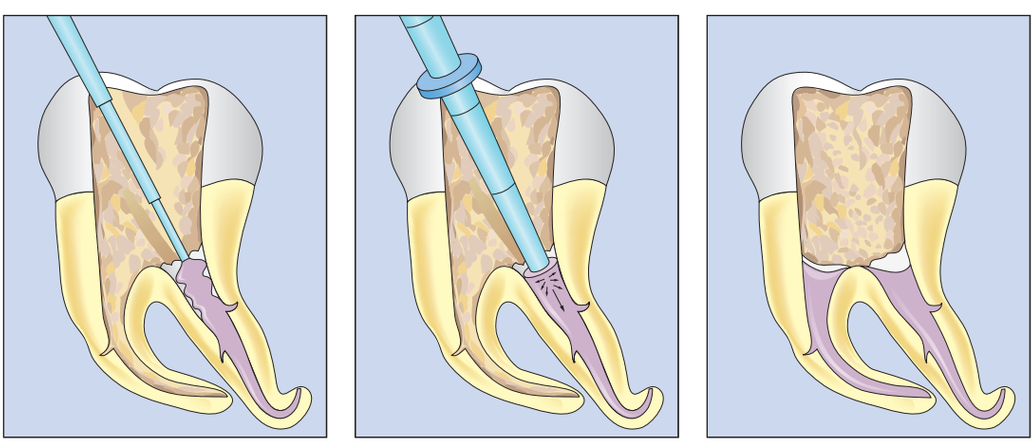


31.10 Application of gutta-percha

Left: Ideally, the silver needle should be placed in contact with the gutta-percha. Leaving in place for approximately 5 seconds before inserting gutta-percha will heat the down-pack superficially, creating a solid seal.

Middle: The warmed gutta-percha can be inserted in small portions or in a single application.

Right: The gutta-percha is compacted with the preselected plugger until it cools. In difficult anatomic situations it is advantageous to first insert a small amount of gutta-percha.

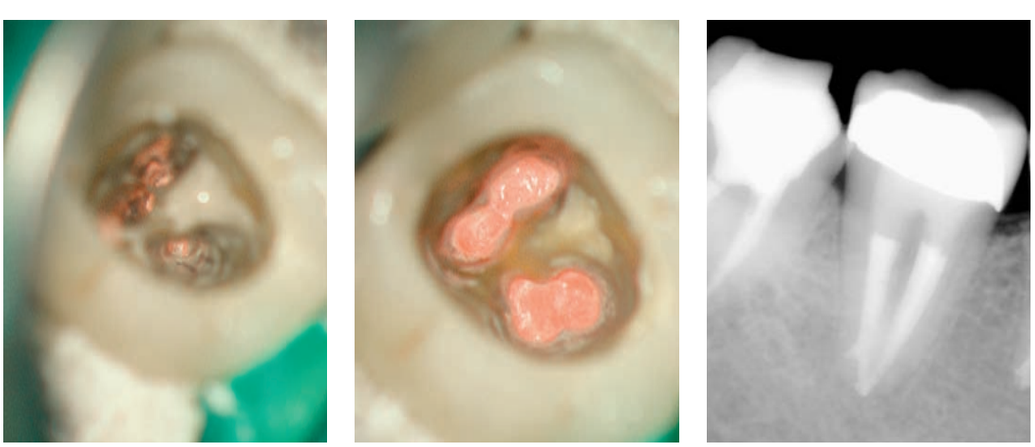


31.11 Backfill and back-pack

Left: During back-packing, light apical pressure is exerted until the applied gutta-percha forces the needle coronally out of the canal.

Middle: Then the entire backfill is compacted until the gutta-percha has cooled, to compensate for any shrinkage.

Right: Ideally the root canal filling should extend coronally to approximately 1 mm apical to the canal orifice.



31.12 Clinical example

Left: View following completed down-pack and before back-packing.

Middle: Cleaned cavity after completion of back-packing and before adhesive restoration.

Right: Postoperative radiograph demonstrating the complex root canal anatomy.

Science and Clinical Application

Obturation techniques using warm vertical compaction of gutta-percha have several advantages over other obturation techniques.

Compared with the lateral compaction technique, warm vertical compaction as well as the continuous wave technique allow the placement of a homogeneous gutta-percha mass with a greater amount of the material and minimal sealer, and no voids in the root canal filling (Wu et al., 2001; Cathro et al., 2003; Lea et al., 2004). These techniques also result in a higher frequency of filling of the lateral, accessory canals (Goldberg et al., 2001).

For an impermeable apical seal, the master cone should be adapted perfectly to the shape of the instrumented root canal. This is dependent on the applied temperature, the duration of heat application, and the depth of insertion of the heat plugger (Venturi, 2002).

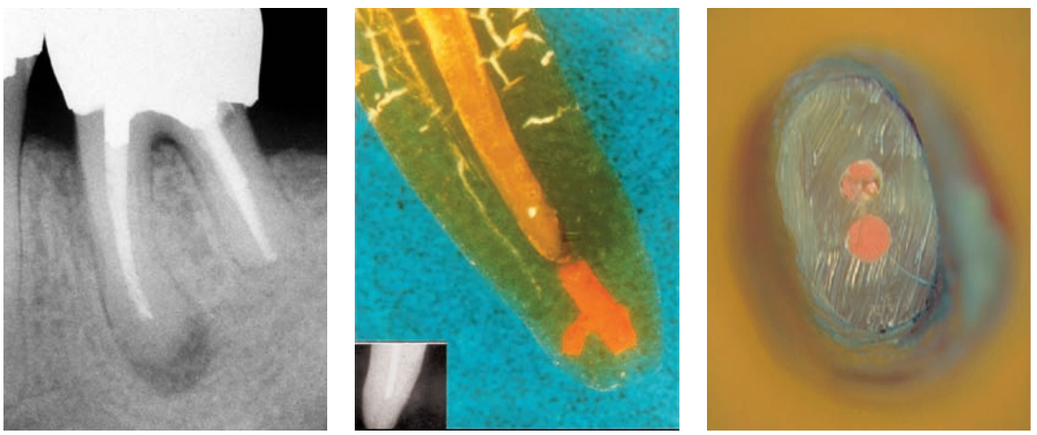
Schilder demonstrated that following warming of gutta-percha to more than 2°C above body temperature and with insertion of the heat carrier and plugger to a point approximately 5 mm coronal to the apex, ideal adaptation of the gutta-percha could be achieved (Schilder, 1967; Marlin et al., 1973; Goodman et al., 1981).

31.13 Clinical case I

Left: Mandibular molar with a short root canal filling (courtesy of Dr. John West).

Middle: Following infusion with red pelican dye, the inadequate canal debridement and seal are obvious (courtesy of Dr. John West).

Right: Transverse section demonstrating the differences between the lateral compaction and the continuous wave techniques with regard to the quantity of gutta-percha in a root canal filling.

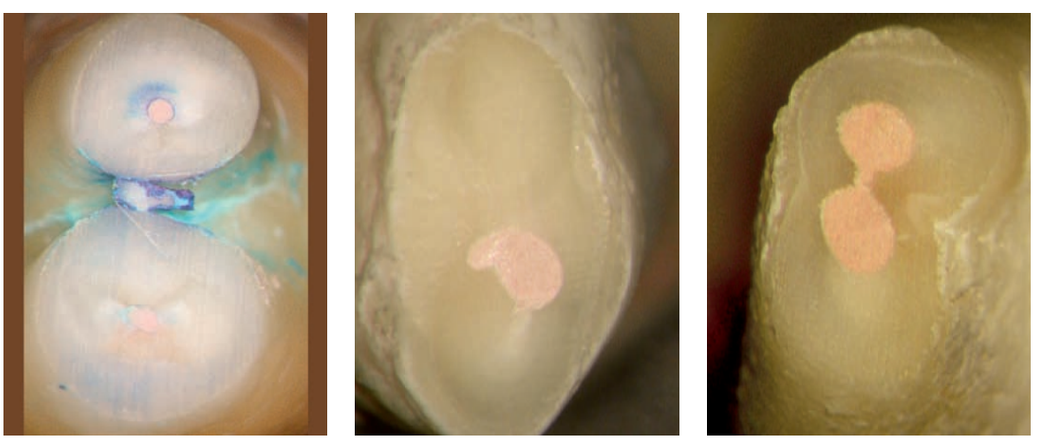


31.14 Clinical case II

Left: Transverse section showing incomplete compaction of the gutta-percha and partial obturation with sealer.

Middle: Another transverse section showing ideal obturation.

Right: Transverse section showing the ideal obturation of an isthmus (courtesy of Dr. Caroline Neumann).

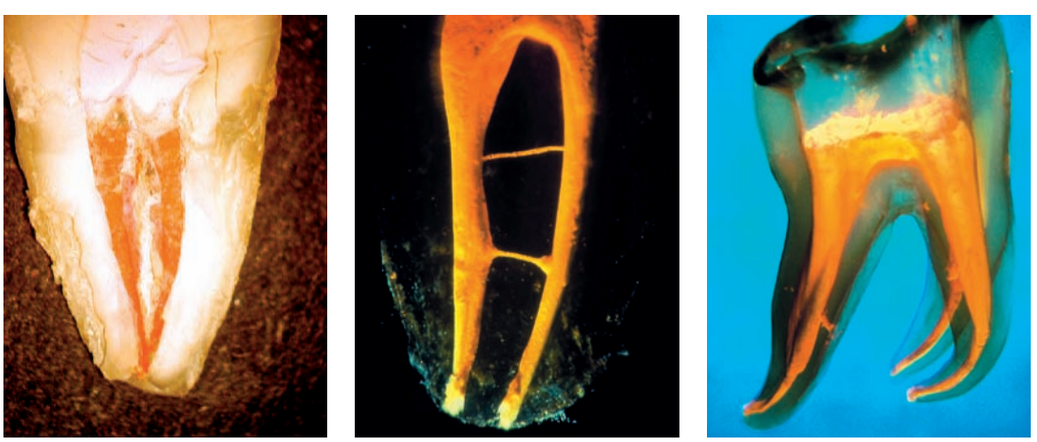


31.15 Clinical case III

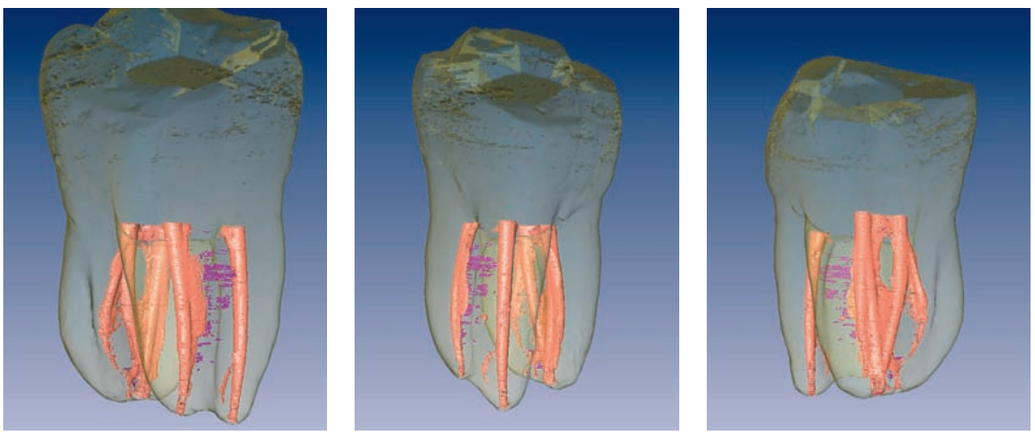
Left: The mesial root of this mandibular molar was treated before it was extracted; it clearly demonstrates precise adaptation at the apical foramen and the entire root canal system.

Middle: This extracted tooth shows the potential of the warm vertical compaction technique.

Right: This extracted tooth was treated endodontically using the continuous wave technique (middle and right illustrations courtesy of Dr. Arnaldo Castellucci).

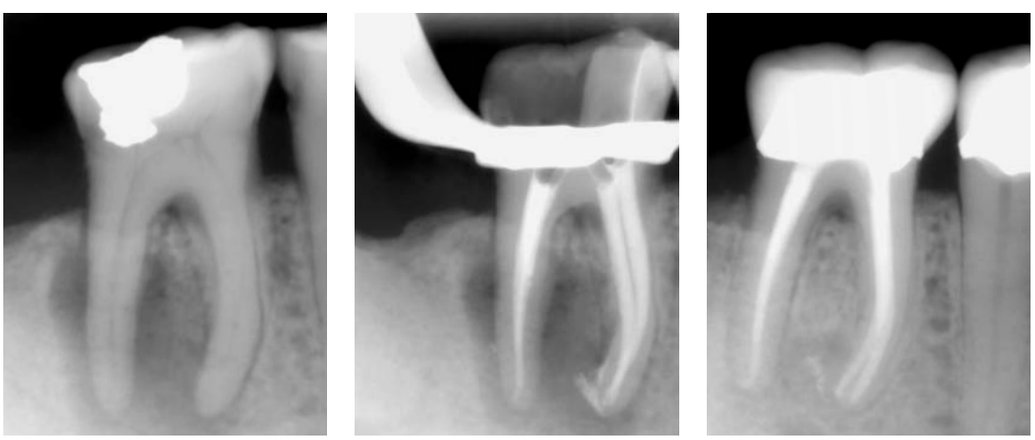


Some authors, however, have concluded that a close positioning of the plugger to the working length and an average temperature increase of 6°C is required for ideal adaptation of the gutta-percha to the root canal walls. A temperature increase of 4°C did not lead to ideal adaptation in the apical region (Villegas et al., 2005). Smith (2000) showed that the insertion of a heat carrier up to 3 mm from the apex was necessary for good adaptation of the master cone on the canal walls. Other authors have suggested that the insertion of a heat carrier deeper than 4 mm before the working length led to better adaptation (Yared, 1995; Bowman, 2002). This can be facilitated by apical preparation using instruments with a larger taper that enable sufficiently deep penetration of the plugger (Diemer, 2006). However, the material should not be too soft in order to allow control of flow of the material.



31.16 3D scan

This extracted tooth was mechanically instrumented and continuously irrigated for 30 minutes with sodium hypochlorite after warm vertical compaction of gutta-percha, then scanned. The pink-colored areas represent the sealer and gutta-percha; the purple-colored regions were not able to be adequately cleaned despite ideal conditions (courtesy of Brown and Herbranson Imaging).

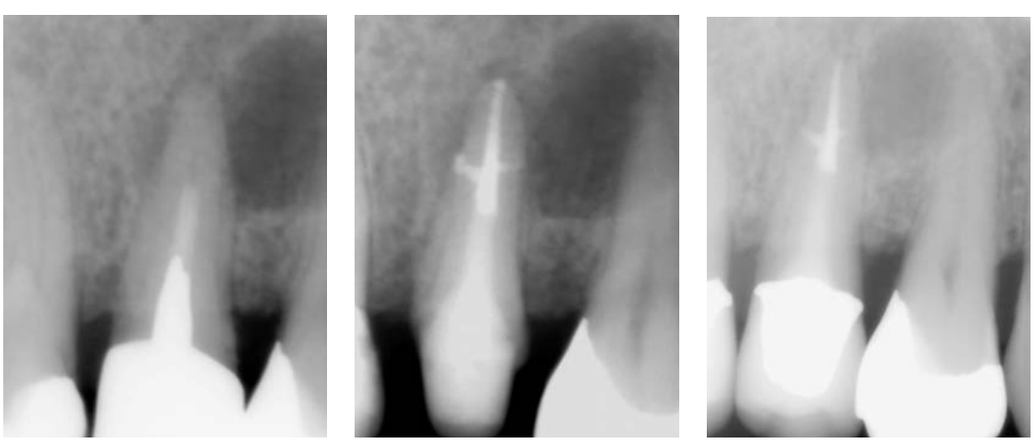


31.17 Large apical lesion

Left: A mandibular molar with an extremely large lesion of endodontic origin.

Middle: The postoperative radiograph shows slight extrusion of sealer.

Right: The follow-up radiograph 5 years later shows complete regeneration of the osseous defect.



31.18 Multiple lateral canals in a maxillary premolar

Left: A root canal treated maxillary premolar with an extremely large lesion of endodontic origin.

Middle: The postoperative radiograph following retreatment shows large lateral accessory root canals.

Right: The follow-up radiograph 6 months after retreatment shows initial regeneration of the osseous defect.

Venturi et al. (2002) demonstrated that the increase of temperature within the apical third of the canal was negligible and that the compaction of the mass of the gutta-percha close to the apex was carried out at normal body temperature.

The rise of temperature from uncontrolled heat application during obturation can cause damage to the surrounding tissues. Obturation using the continuous wave technique has been shown not to raise the root surface temperature by more than the critical amount, suggesting no danger for the surrounding tissues (Silver et al.,1999; Venturi et al., 2002). The ability of an obturation technique to fill the root canal system three-dimensionally depends partially on the timing and intensity of force application. With regard to vertically applied forces during root canal obturation, the continuous wave technique is one of the best techniques (Blum et al., 2001).

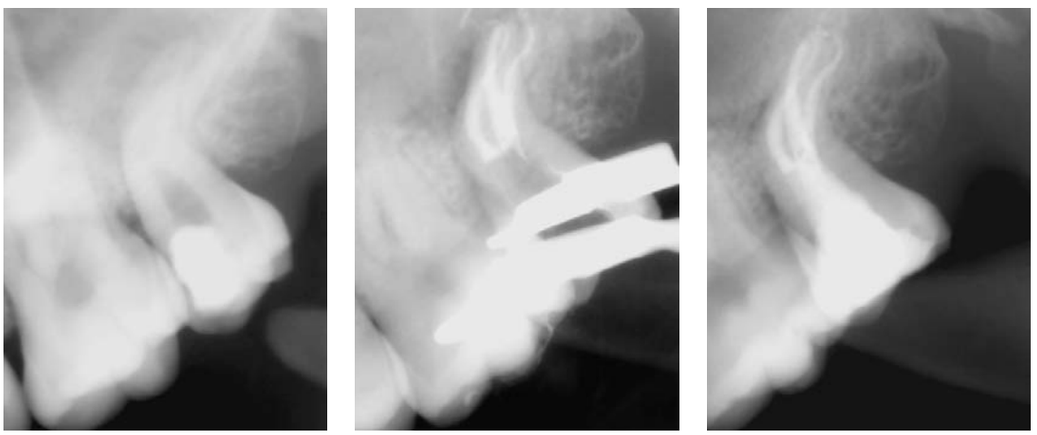
With regard to leakage around or within the root canal filling, lateral compaction is associated with more rapidly developing coronal leakage than the continuous wave technique (Jacobson et al., 2002). In terms of efficient use of time, the continuous wave technique requires less clinical time than the warm vertical compaction or lateral compaction technique (Silver et al., 1999; Kececi et al., 2005).

31.19 Extreme dilaceration of the apical third of the root

Left: An extremely curved maxillary molar root with a large lesion of endodontic origin.

Middle: Postoperative radiograph clearly showing the complex anatomy.

Right: Follow-up radiograph taken 1 year later demonstrates complete regeneration of the defect.

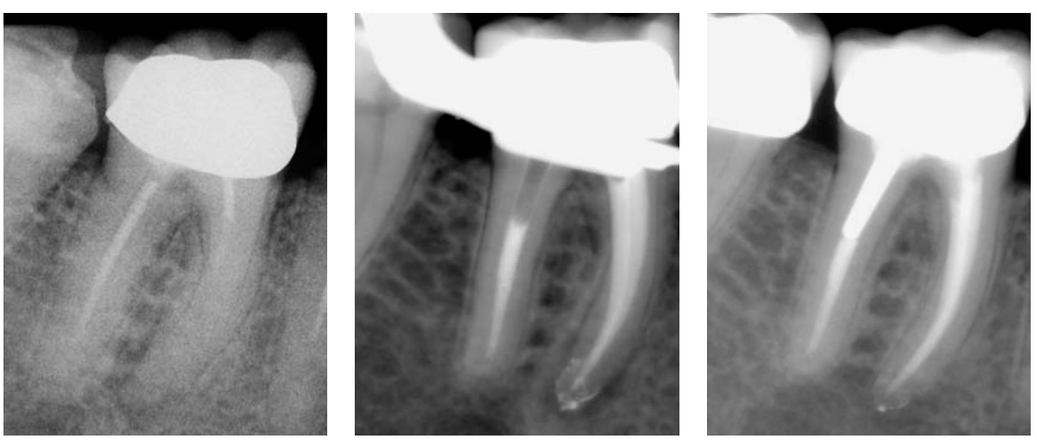


31.20 Retreatment, mandibular molar

Left: A mandibular molar with a lesion of endodontic origin.

Middle: Postoperative radiograph showing minor extrusion of sealer at the apex.

Right: Follow-up radiograph 5 years later showing complete regeneration of the defect.

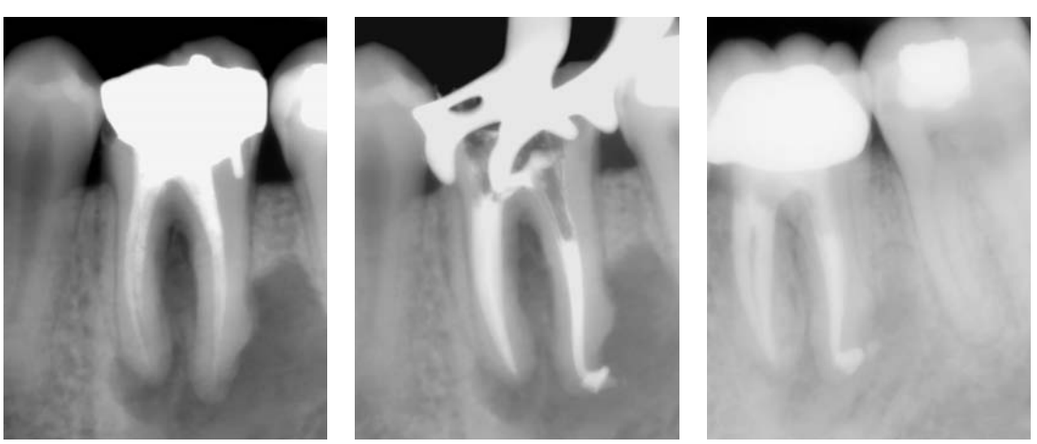


31.21 Large apical lesion

Left: A mandibular molar with an extremely large lesion of endodontic origin following inadequate root canal treatment.

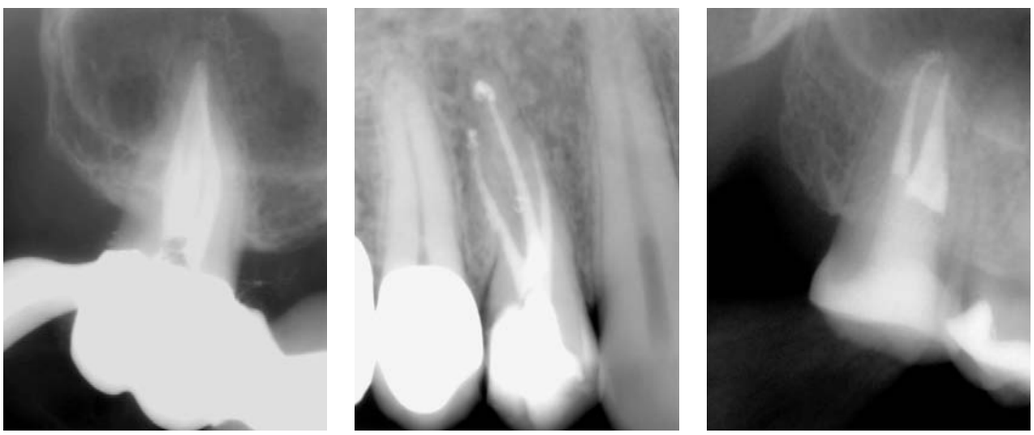
Middle: Postoperative radiograph following retreatment showing slight apical extrusion of the sealer.

Right: Follow-up radiograph 1 year later showing complete regeneration of the defect.



In addition, in clinical studies, the treatment method used appears to influence the treatment results. In phases 2, 3, and 4 of the Toronto study (Farzaneh et al., 2004; Marquis et al., 2006; de Chevigny et al., 2008) instrumentation using a flared preparation in combination with warm vertical compaction led to a higher rate of healing compared with the group treated by stepback preparation and lateral compaction. The risk of extrusion of root canal filling material is higher with the warm vertical compaction technique and the continuous wave technique than with lateral compaction (van Zyl et al., 2005; Marquis et al., 2006) and is operator dependent.

Several authors have described obturation using injection-molded, thermoplasticized dental gutta-percha with the Obtura gutta-percha gun without prior down-packing of gutta-percha (Fulton et al., 1977; Marlin et al., 1981). Tani-Ishii et al. (2003) reported good healing results using apical down-packing with the Obtura II gun.

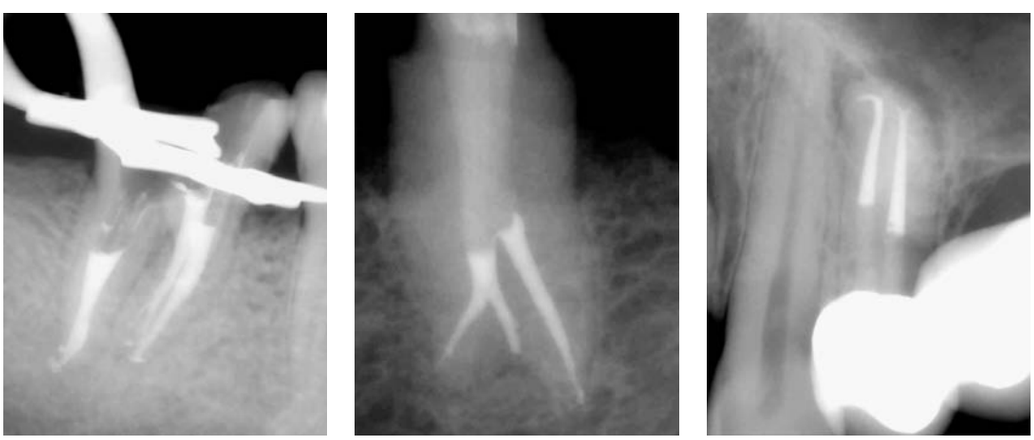


31.22 Anatomic anomaly

Left: Fused root canals are an ideal indication for use of the warm vertical compaction technique.

Middle: In this three-rooted maxillary premolar, the continuous wave technique was used.

Right: The "interesting" root canal anatomy of this maxillary molar presents an ideal indication for the use of the warm vertical compaction technique.

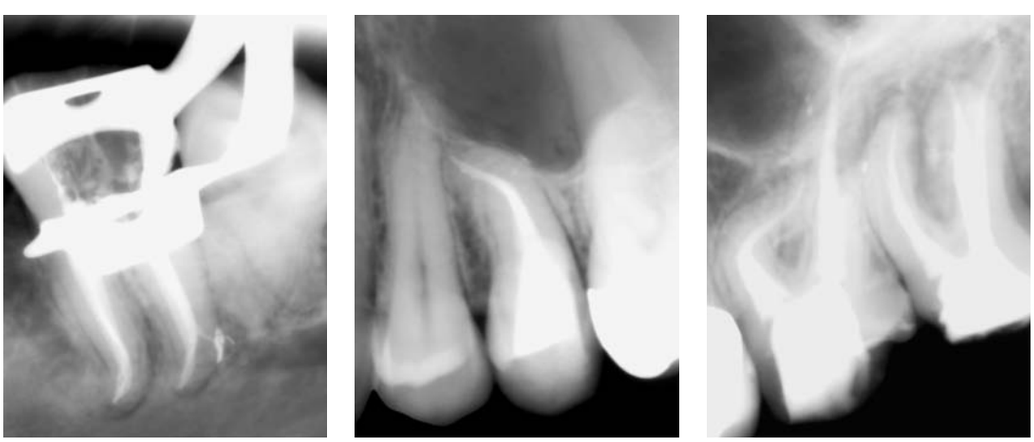


31.23 Arborization along the course of the root canal

Left: The continuous wave technique was successful in filling the branches of this root canal.

Middle: The forked apical segment of this root canal was successfully obturated.

Right: The unusual root canal anatomy of this maxillary premolar was obturated using the warm vertical compaction technique.



31.24 Moderate to severe dilaceration

Left: A mandibular molar with moderate curvature in the apical segment and a lateral canal.

Middle and right: The 90° bend in the maxillary premolar and molar necessitated prebending the instruments for ideal obturation.

32 Thermafil

As early as 1978, Johnson published the concept that gutta-percha could be inserted into the root canal using a carrier device. The system became known as Thermafil; however, the first version had some problems (metal carrier, gutta-percha too hard/soft, post build-up, etc.) (Baumann, 2005).

The new Thermafil (TF) system consists of Thermaprep plus oven, TF points, verifiers, Thermacut, and the post space bur. First, the size and shape of the prepared canal is ascertained using the verifier. The TF pin should have the same diameter as the master apical file and stop 0.5–1 mm shorter than the working length (Cantatore, 2006). The use of a sealer is obligatory, whereby the hot gutta-percha may alter the chemical composition of some sealers. The oven permits rapid and precise heating of the TF points, which always possess a plastic core.

The heated TF point must be slowly but continuously inserted apically within 10 seconds (Levitan et al., 2003) and held in position by finger pressure. Severing off any excess material is not a problem using the Thermacut. Additional points are easy to fit with the post space bur.

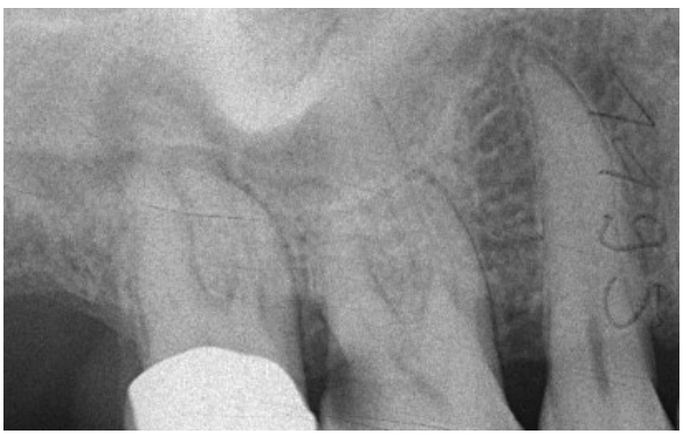
32.1 Thermaprep plus oven

The new warming device reliably heats the Thermafil point in only a few seconds.

Right: The verifier is a ProFile instrument with a hand grip. It is a useful tool to evaluate the size and shape of the root canal. The corresponding Thermafil point provides an appropriate amount of gutta-percha.

32.2 Diagnostic radiograph

Tooth 16 has extensive caries distally and apical lesions are associated with all three roots. Tooth 17 has been treated with a full crown and the radiograph shows an essentially spherical lesion around the palatal root.

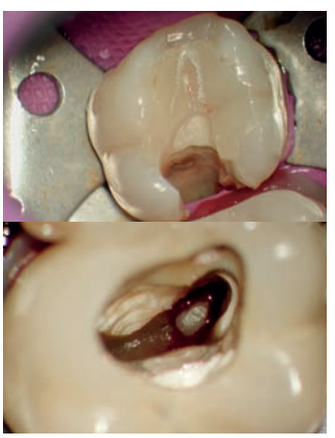


32.3 Initial clinical view

In this occlusal view, the ceramic inlay on tooth 16 appears intact, but the metal base of the crown on tooth 17 is a little exposed.

Top right: Following opening of the pulp chamber, a large and deep carious defect is evident in tooth 16.

Bottom right: Within the pulp chamber of tooth 17 is a spherical pulp stone (center).

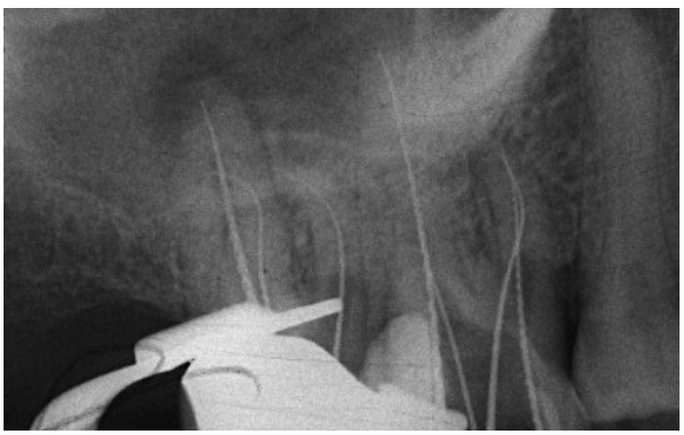


Numerous investigations have demonstrated that, following a period of training, TF is a rapid, reliable, and excellent root canal filling method (Baumann, 2005). Studies evaluating sealing quality have shown the same or even better results than with lateral or warm vertical compaction if the smear layer is removed and a sealer used (Pommel and Camps 2001; Guigand et al., 2005).

The early problem regarding exposure of the plastic core is no longer an issue today because of a more severely tapered canal preparation (Guigand et al., 2005).

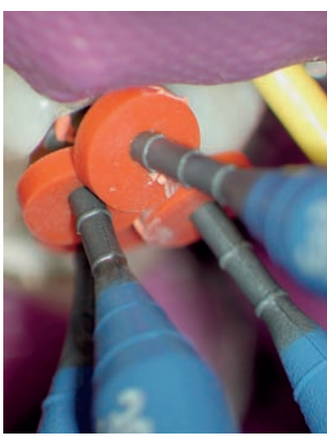
Apical extrusion of sealer and/or gutta-percha can be avoided or at least well controlled with practice, careful working length measurement, TF pin selection, use of small amounts of sealer, and a preparation of appropriate size and shape (Baumann, 2005; Cantatore, 2006).

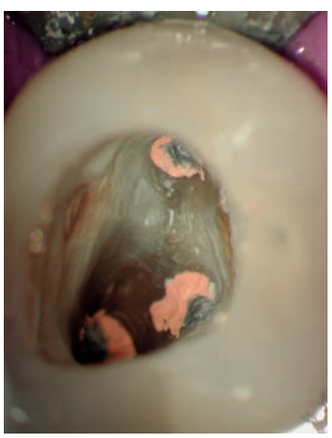
It is of interest that Thermafil, Ultrafil, and MicroSeal do not contain pure α-gutta-percha, but rather a mixture of β-gutta-percha and amorphous forms, as shown by magnetic resonance imaging (MRI) analysis and infrared spectrometry (Camerucci, 2003).



32.6 Length determination radiograph

The first molar has four root canals, and the second molar has three. With this angle of projection, the root curvature for the second molar is clearly visible, while in the first molar, mb1 and mb2 cannot be differentiated and the distal root is practically hidden by the palatal root.





32.5 Root canal filling

Left: TF carriers were inserted into all four root canals of the first molar.

Middle: Pulpal floor after cleaning. All four of the filled canal orifices are visible.

Right: In the second molar, mb1, db, and pal have been filled. The "white line" did not lead to the orifice of an additional canal despite careful examination.

32.4 Radiographic follow-up

All seven root canals have been filled up to the root apices.

33 Gutta-percha Substitute: Resilon

Resilon was introduced to the market in 2003 (Resilon Research LLC, Pentron, Wallingford, CT, USA). Instead of gutta-percha, Resilon points are made of a thermoplastic polymer — a material that simulates completely the well-known and reliable treatment characteristics of gutta-percha. Of note is that not only is there material deformation on heating, but also actual melting. The sealer consists of methacrylate filled with bioactive glass and calcium hydroxide. A bonding agent is also used to improve the adhesion between the sealer and dentin.

The Resilon points are available in three tapers (.02, .04, .06) and in ISO sizes 15–60, and as accessory points (from extra fine to large) as well as Obtura pellets.

Any of the recognized techniques can be used for obturation (single cone, lateral, or warm vertical compaction).

In the midst of controversial discussions regarding long-term success of treatment with Resilon, Hiraishi et al. (2007) in their study "Shear bond strength of Resilon to a methacrylate-based root canal sealer" demonstrated a favorable outcome with the Resilon product. They also concluded that it was important to use a slow, dual-hardening sealer with decreased polymerization dynamics, which minimizes shrinkage.

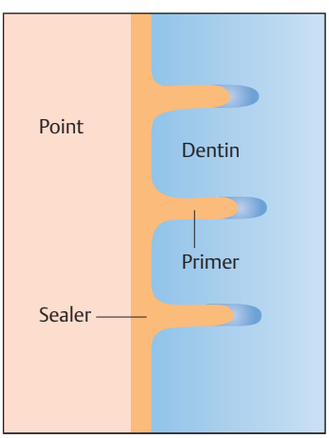
33.1 RealSeal kit

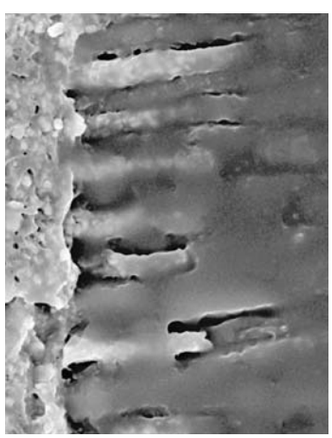
The RealSeal kit (SybronEndo, CA, USA) contains, depending upon the version (intro, .02, .04, or .06), primary or accessory points, sealer, primer, microapplicators, and additional accessory components.

33.2 Resilon as RealSeal

Left: In comparison with other sealers, the RealSeal sealer penetrates further into the radicular dentinal tubules (Patel et al., 2006).

Right: SEM image of sealer tags from RealSeal.





The susceptibility of Resilon root canal fillings to microbial leakage is significantly less in comparison to standard gutta-percha fillings (in vitro studies using *Streptococcus mutans* and *Enterococcus faecalis*; Shipper et al., 2004). Using the "fluid filtration technique," the sealing ability of the adhesive cone was shown to be higher compared with conventional gutta-percha obturation (Stratton et al., 2006; Tunga et al., 2006).

The bond between a Resilon root canal filling and the intraradicular dentin appears to be significantly better than conventional gutta-percha fillings (Skidmore et al., 2006: "Micropush-out bond strengths test"). Less periapical inflammation has been observed with Resilon root canal fillings, leading to the conclusion that apical leakage is less than with conventional gutta-percha fillings (Shipper et al., 2005).

33.3 Clinical case I

Pre- and postoperative radiographs of a mandibular molar (middle: postoperative orthoradial projection; right: postoperative distal eccentric projection).

33.4 Clinical case II

Left: Preoperative radiograph of a maxillary right molar.

Middle: Postoperative radiograph after warm vertical compaction — rubber dam in situ.

Right: 12-month follow-up radiograph showing healing.

33.5 Clinical case III

Left: Microscopic view of the palatal root canal orifice.

Middle: Microscopic view: mb1, mb2, distal canal orifice.

Right: Clinical view following completion of endodontic treatment.

33.6 Clinical case IV

Left: Preoperative radiograph of a mandibular first molar.

Right: Distal eccentric projection following completion of root canal filling and coronal sealing.

34 GuttaFlow

A root canal sealer has to fulfill several criteria:

- It should provide impermeable, long-lasting sealing of the root canal system.
- The material must be easy to apply.
- The setting time should be appropriately short to permit further treatment of the tooth, for example the insertion of a root canal post, in the same sitting.
- If necessary, the material should be easy to remove in the event of retreatment.
- The components of the sealer should not lead to any problem with the subsequent adhesive restoration.
- Finally, the chemical composition of the material should not elicit any soft-tissue irritation at the periapical region if extrusion occurs.

With regard to the studies that have been performed to date, GuttaFlow (Coltène Whaledent, Langenau, Germany) seems to fulfill these requirements.

Based on the addition curing silicone sealer RoekoSeal Automix, the GuttaFlow system is the first sealer that provides microscopically small, approximately 30 µm, gutta-percha particles and combines both components of gutta-percha and sealer. GuttaFlow flows at room temperature, so its characteristics and capabilities are quite different from those of the more classic root canal filling pastes.

To date, the requirement was that the layer of the sealer should be as thin as possible in order to efficiently minimize shrinkage and solubility. However, the single-cone technique is explicitly recommended for obturation with GuttaFlow.

The practically nonexistent solubility and volume stability of GuttaFlow marks a new chapter in the development of root canal filling pastes. The silicone-based GuttaFlow is a nonresorbable root canal filling paste for the cold obturation of root canals.

The development of RoekoSeal for the obturation of root canals paved the way for long-term sealing (Wu et al., 2002) that is also reliable in a moist environment (Roggendorf et al., 2007). With regard to biocompatibility, silicone is to a great extent the reference material. For biocompatibility testing, silicone tubes are implanted subcutaneously in order to assess the tissue compatibility of materials contained therein. Silicone sealers are virtually insoluble in water and saliva (Schäfer et al., 2003). RoekoSeal showed no cytotoxic characteristics in cell cultures (Miletic et al., 2005), and it exhibited only slight expansion (Ørstavik et al., 2001).

The coronal seal obtained with silicone-based sealers for obturation without gutta-percha points as backfill is very good (Whitworth and Baco, 2005). The excellent sealing capabilities of RoekoSeal have been demonstrated in numerous experimental studies (Ebert et al., 1999; Roggendorf et al., 2001, 2003; Bouillaguet et al., 2004). However, RoekoSeal is not antibacterial (Cobankara et al., 2004). Therefore Nanosilver was added to GuttaFlow as an antibacterial component.

Scanning electron microscopic (SEM) studies of the homogeneity as well as the adaptation of GuttaFlow have demonstrated its qualities in comparison to conventional sealing materials (El Ayouti et al., 2005). The initial (Roggendorf et al., 2001; Brackett et al., 2006) as well as long-term (Taranu et al., 2005) quality of the seal was considered to be quite good.

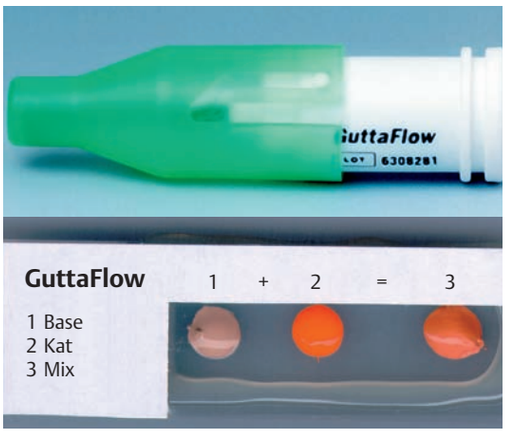
Cytotoxicity tests (Gambarini et al., 2003; Bouillaguet et al., 2006; Eldeniz et al., 2007) have demonstrated the excellent tissue compatibility of GuttaFlow.

Practical Application of GuttaFlow

The procedure of obturation of the root canal system using GuttaFlow is no different to when using more classic root canal sealers. GuttaFlow is available commercially in a capsule, which is activated by compressing the cap, removing it, and subsequently placing the capsule in an amalgamator for mixing for 30 seconds. Then the capsule is put into the dispensing device and, after removal of the pin, the plastic cannula provided with the kit is attached to the capsule with a Luer Lock mechanism.

In this way, the previously prepared root canal can be slowly filled, beginning from the apical end, while the cannula is progressively withdrawn from the root canal. For the placement of GuttaFlow the attendant cannula as well as the double-dip technique is recommended. Due to the risk of apical extrusion, lodging of the cannula within the canal should be avoided.

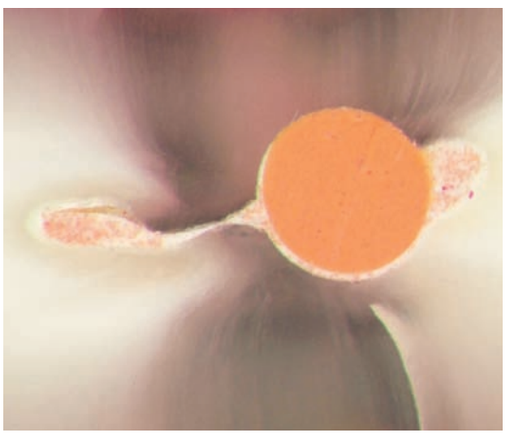
Obturation of the root canal with only GuttaFlow and no additional gutta-percha point may be associated with problems with regard to the control of filling of the apical region and is therefore not recommended. On the other hand, GuttaFlow with a coronal backfill without a gutta-percha cone provides excellent closure and sealing.

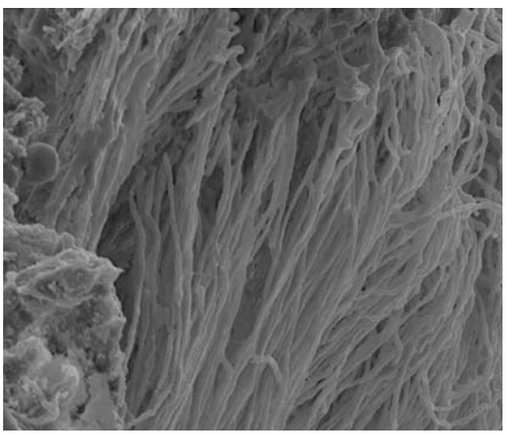


34.1 The GuttaFlow system

Left: The clinical application device with capsule and attached cannula. The inset (lower left) depicts the flow of gutta-percha following trituration.

Right: The GuttaFlow capsule before activation. Following compression of the cap and slight rotation, the cap is removed and the capsule is placed in the triturator. The lower panel depicts the individual components as well as the correct color following trituration.

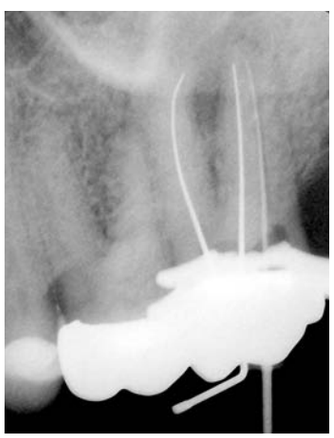


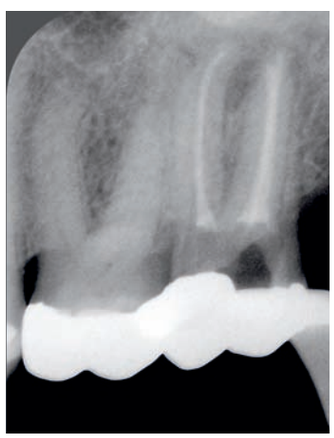


34.2 Flow characteristics

Left: A root canal cross section, following obturation using the single-cone technique, demonstrates the excellent flow characteristics of the GuttaFlow system. Also seen here, the noninstrumented second root canal, as well as the isthmus, has been completely filled in vivo with the GuttaFlow system, including the recess of the instrumented root canal.

Right: SEM image demonstrating very good penetration of GuttaFlow into the dentinal tubules (single-cone technique) (courtesy of J. Ebert).





34.3 Radiograph documentation

Left: A diagnostic radiograph reveals a periapical lesion on tooth 27.

Middle: The radiograph to determine the working length does not reveal any unusual canal anatomy. The root canal was prepared with NiTiFlex instruments to ISO size 50.

Right: The root canal filling is clearly visible up to the apical stop. The GuttaFlow filling material did not extrude beyond the apex.

35 Coronal Seal/Leakage

Wound infection is a possible complication during or following any surgical procedure. The same principle is valid for all endodontic procedures. In addition, infections may occur later as well, owing to the presence of bacteria in the oral cavity.

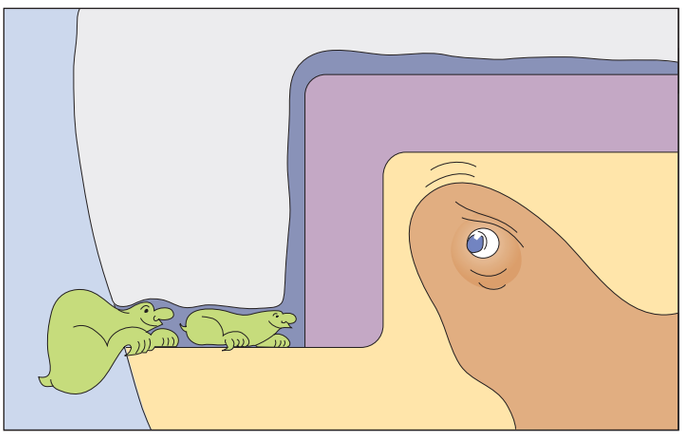
Restorations with margins that prevent bacterial ingress are desirable, but this clinical goal remains difficult to achieve. Periradicular periodontitis may occur after root canal therapy if microorganisms invade the root canal system. This is a major cause of failure following root canal treatment (Ray and Trope, 1985).

The American Endodontic Association defines coronal leakage as the entry of oral fluid and microorganisms into the gap between a restoration and hard substance of the tooth. In vitro studies have demonstrated that microorganisms and their toxins can penetrate endodontically treated root canals in as little as 6 weeks (Swanson and Madison, 1987).

The term apical leakage refers to the seepage of tissue fluids from the periapical region into instrumented and filled root canals. These tissue fluids provide nutrition for any micro organisms not removed during root canal preparation and filling, enabling them to survive in the root canals.

35.1 Coronal leakage

Schematic diagram of coronal leakage in the margin of a restoration in a tooth with a vital pulp. Pulp tissues can inhibit the entry of microorganisms by the externally directed flow of dentinal fluid and by specific immune host defense reactions. However, after root canal treatment, microorganisms may advance uninhibited into the root canal system.



35.2 Entry points for microorganisms

Scanning electron photomicrographs (left, middle) and a histologic preparation (right) show possible paths for oral microorganisms to enter root canal systems.

35.3 Clinically inadequate restoration

Typical clinical view of a molar with a large amalgam restoration, subsequently “repaired” with a composite restoration. Poorly sealed and/or open margins in such inadequate restorations often lead to pulpal inflammation.

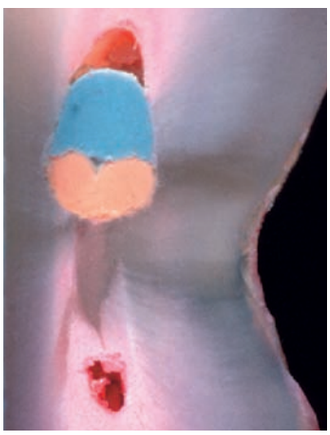
Clinical Causes

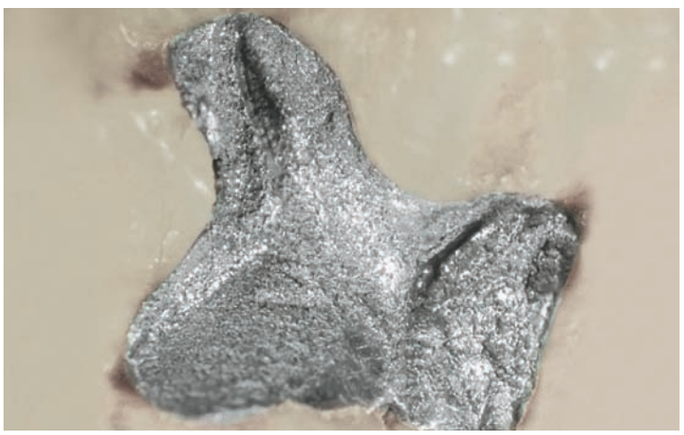
Microleakage can occur in any endodontically treated root canal. Because of the larger size of posterior restorations and the higher masticatory forces in this region, multirooted teeth are more often affected than single rooted teeth (Saunders and Saunders, 1990).

The quality of both the coronal restoration and the root canal filling influence the occurrence of leakage. Inadequately instrumented canals provide niches for survival and recolonization of the remaining bacteria.

Poorly adapted temporary, or poorly fitted definitive, crowns also increase the likelihood of microleakage. The same is true for inadequate temporary restorations. Current thinking is that the interval between completion of root canal therapy and placement of the definitive restoration should be as short as possible to minimize the possibility of microleakage.

Controversy exists in some circles regarding the recommended removal of the smear layer following root canal preparation. However, it seems certain that the presence of a smear layer not only inhibits root canal disinfection but also promotes the occurrence of leakage.





35.4 Leakage

Insufficient margins of amalgam restorations permit colonization of bacterial plaque, which primarily consists of Gram-positive bacteria, as well as Gram-negative bacteria such as *Fusobacterium nucleatum*. The toxins produced by such microorganisms are responsible for the effects of microleakage.

Left: Cross section through an inadequately filled mandibular anterior tooth exhibiting areas ideally suited for microbial colonization. Different colored gutta-percha points are used.

35.5 Deficient crown margins

Clinical view of definitive anterior maxillary crowns placed on endodontically treated teeth. The marginal adaptation is poor and the luting material has been washed out. These defects are easily detected in crowns with supragingival coronal margins. However, deficient subgingival crown margins often remain undetected. Even temporary crowns should provide a secure marginal seal.

35.6 Infection and reinfection

Left: Vertical section through a tooth following root canal instrumentation in vitro, showing areas of dentinal debris and some evidence of a smear layer in the apical third of the root canal. Such remnants within the root canals should also be removed.

Right: Reinfection will occur if saliva enters the canal during placement of a post build-up. About 5 mm of root canal filling material should always be left within the canal, apical to the post. The luting procedure should always be carried out using rubber dam.

Avoiding Leakage/Microleakage

The use of rubber dam during an endodontic procedure provides an excellent antiseptic environment and reduces salivary contamination when using an adhesive restorative technique. The cementation of post and core, if necessary for subsequent definitive restoration, should also be carried out under rubber dam.

Very important for long-term success is the placement of the definitive restoration within a 1.5–2-mm wide area of healthy tooth hard structure ("ferrule effect"). In cases with a small biologic width, this is often only possible following a periodontal crown-lengthening procedure.

In addition to optimizing restoration margins, microleakage can also be prevented by sealing the orifices of filled root canals before placing the definitive restoration. Such an intracoronal barrier can be created using a light-curing bonding material or a thinly mixed glass ionomer cement. Furthermore, post-endodontic bacterial penetration can also be reduced using an adhesive technique for build-up restorations.

Studies have shown that both the endodontic treatment and prompt restoration are critical for clinical success.

35.7 Sealing

Left: The orifices of the distobuccal and both mesiobuccal canals of a maxillary first molar immediately before sealing with a bonding material. This multilayered seal prevents the invasion of filled root canal systems by microorganisms and oral fluids (courtesy of Dr. Andreas Bindl).

Right: The root canal orifices of a maxillary molar are covered with a bonding material; the coronal dentin is prepared prior to placing an adhesive CEREC endocrown (Sirona Dental Systems, NC, USA) (courtesy of Dr. Andreas Bindl).

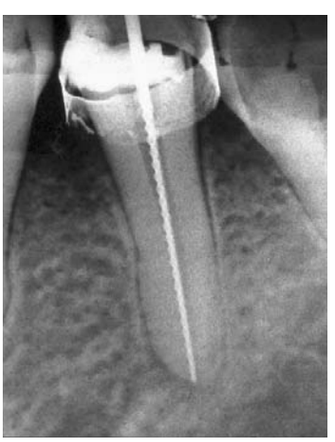
35.8 Follow-up radiograph

Two-year radiographic follow-up after placement of a CEREC endocrown with Dual cement. The periodontal ligament space is even throughout, and the patient reported no clinical symptoms. (Courtesy of Dr. Andreas Bindl).

35.9 Coronal leakage

Left and middle: Missing enamel and dentin can be built up with composites or by using orthodontic bands. In patients in whom rubber dam clamps cannot be applied, other materials can be used, such as Wedjets.

Right: Radiograph of a maxillary second molar showing that the root canal and lateral accessory canals are homogeneously filled. However, the success of this treatment is greatly endangered by the obvious coronal leakage (courtesy of Dr. Marco Ackermann).

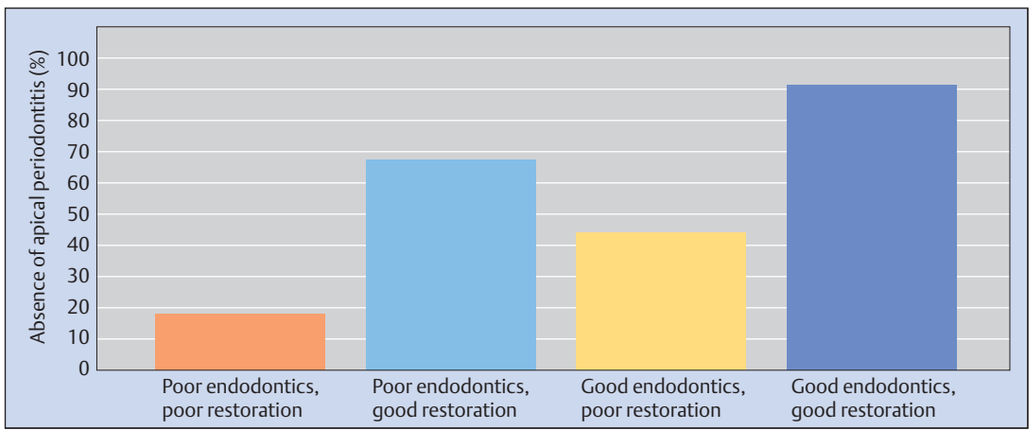


Studies of Coronal Microleakage

Swanson et al. (1987) first described the mechanism of coronal leakage. Since then, many studies have discussed the possible influence of oral microorganisms that may invade root treated canal systems. Previously, most interest was focused on the apical seal of the root canals.

Toward the end of the twentieth century, two studies in the USA and Norway, based on radiographs, evaluated the success of endodontic treatments compared with the associated coronal restorations. Although the results of the two studies varied, the cumulative success rates were similar (61% and 67% respectively, Ray and Trope, 1995, Tronstad et al., 2000). The most important conclusion drawn from the two studies is that both treatment phases — endodontics and the coronal restoration — must be fully adequate to optimize periapical healing.

However, it is important to note that Ricucci and Bergenholtz (2003) could not confirm this relationship. In their study, teeth exposed to the oral cavity exhibited no particular risk of periapical periodontitis.

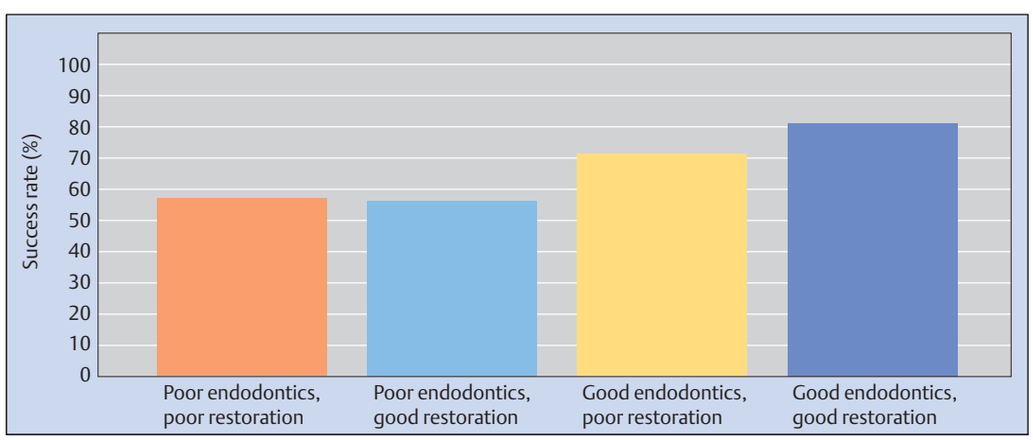


35.10 Influence of the quality of the restoration and endodontic treatment (Ray and Trope, 1995)

Success rates in 1010 teeth with an original diagnosis of periapical periodontitis 1 year following root canal treatment (Ray and Trope, 1995). Data based on radiographic parameters. Conclusions: The technical quality of the postendodontic restorative treatment was more important for periapical healing than the endodontic therapy itself.

35.11 Influence of the quality of the restoration and endodontic treatment

A good coronal restoration can prevent coronal leakage even if the endodontic treatment (left) is less than perfect. The combination of poor endodontic treatment and a poor restoration (right) yields the poorest outlook for clinical success.



35.12 Influence of the quality of the restoration and endodontic therapy (Tronstad et al., 2000)

Success rates in 1001 teeth with an original diagnosis of periapical periodontitis, 1 year following root canal treatment (Tronstad et al., 2000). Data based on radiographic parameters.

Conclusions: The technical quality of the endodontic therapy was more important for periapical healing than the postendodontic tooth restoration.

Postendodontic Procedures

F

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36 Conventional Postendodontic Therapy

Root canal posts are used in the reconstruction of endodontically treated teeth that have extensive coronal defects to serve as an anchor for any build-up or for enhancing retention of the definitive restoration. However, the preparation of the root canal for the post space, and the subsequent functional load transfer via the post represent a potential risk to the integrity of the tooth root. This risk, which could, for example, lead to a vertical root fracture, should be kept as low as possible. Thus it must be kept in mind when planning postendodontic therapy that *not every* endodontically treated tooth must be restored using a post.

Whether a root post restoration will be required depends on the extent of the coronal defect and the expected occlusal loading (Schwartz and Robbins, 2004; Bolla et al., 2007). If the decision is made to incorporate an intracanal post, it should be constructed in such a way that the root is not excessively weakened; there will always be a trade-off between preserving the tooth substance and achieving maximum possible retention of the post.

Decisions about the design of the restoration and the materials to be used must be made on a case-by-case basis, as well as decisions about the dimensions of the root canal post and the luting agent to be used. Although the use of fiber-reinforced composite posts cemented with composite materials followed by a coronal build-up is currently very popular, the more traditional metal posts have maintained their prosthodontic value.

The goal is timely reconstruction of the endodontically treated tooth with a cusp-stabilizing definitive restoration so that the tooth is capable of withstanding functional load, and cusp fracture or bacterial microleakage is prevented (Ray and Trope, 1995). A root post is only indicated in the case of a large coronal defect and reduced strength of the dentinal walls post preparation.

It is not the post itself but rather the crown surrounding the dentin core that stabilizes the tooth — the so-called "ferrule effect" — (Isidor et al., 1999). In fact, the use of a post actually weakens the root due to additional loss of hard tissue substance, and increases the risk of perforation during final preparation. If transfer of the functional load from the post to the root results in root fatigue, the root may undergo a vertical fracture and the tooth may have to be extracted.

Therefore, passive, tapered posts, selected on the basis of the available root length and diameter, have proved most successful (Morgano, 1996; Lambjerg-Hansen and Asmussen, 1997; Nergiz et al., 2002). In contrast to the active screw-type posts, which are associated with the development of tensile forces at the end of the flank of the threads, the retention of passive posts is achieved via friction between the parallel walls of the preparation and the post surface, following cementation. Using the correctly shaped preparation instruments, tapered, passive posts can be snugly fitted against the root canal walls with a cement thickness of approximately 50 µm (Schmage et al., 2005).

As their shape conforms to the shape of the root canal, tapered posts — as opposed to cylindrical posts — can be inserted deeper within the canal. The advantage of this is that the functional load from the post can be distributed over a larger area of the root. Tapered posts must, however, be supported at their coronal end by the floor of coronal pulp cavity to avoid the "wedge effect" (Hofmann 1988). Although their retention is inferior to threaded posts, it can be markedly increased by mechanical microretention such as sandblasting the post surface or roughening the root canal wall, accurate fitting of the post, or chemical conditioning of the post (Nergiz et al., 1997; Sahafi et al., 2003; Schmage et al., 2006).

The retention of passive, tapered post systems has proved to be clinically adequate as long as the post length is at least as long as the crown height and a crown preparation at least 2-mm wide is made in the dentin (Smith and Schuman, 1997; Rosentritt et al., 2000). Decementation of the post build-up, and subsequent failure of the restoration, is generally the result of using a short post.

For cementing the post, fine-powder zinc oxide phosphate cement has been used successfully for decades, but composite cement is also indicated for cementing metal posts, and it provides a better seal against microleakage (Schmage et al., 2004).

Prefabricated Titanium Posts

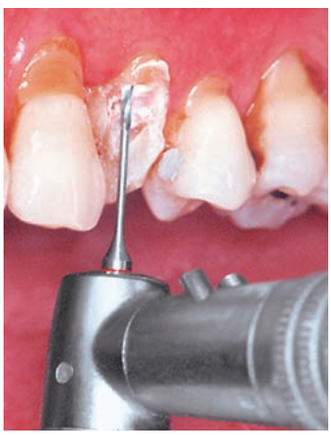
Prefabricated posts of drawn titanium with a retentive head can be placed in a single sitting and built up with an appropriate composite resin material. In contrast, individual "post-and-core" posts must be cast in a dental laboratory and require at least two clinical appointments.

Prefabricated posts that fit well against the dentin of the root canal walls are indicated for round root canals. However, individually cast posts are preferred for canals with an oval or slitlike lumen or exaggerated flare (Maccari et al., 2007).

Titanium posts are available in various lengths and diameters (Hofmann, 1985). The post space is prepared using the appropriately shaped instruments up to the point where the prefabricated post fits snugly against the root canal walls. The retentive head of the post must rest securely against the flat floor of the coronal pulp cavity floor.

Fine-grain zinc oxide phosphate cement has proved effective in the fixation of posts. Sandblasted post, surfaces in combination with roughened root canal walls improve retention.

For coronal build-up of the post, autopolymerizing or dual-cure composite resin is recommended; glass polyalkenoate cement should not be used (Cohen et al., 1998; Akisli et al., 2003; Reill et al., 2008).



36.1 Preparation of the post space

Demonstrated here with the ER System (Komet, Lemgo, Germany).

Left: Reduction of the root canal filling to accommodate the post length so that a minimum 4 mm of root canal filling material remains apically.

Right: Preparation of the flat surface to support the head of the post.

36.2 Preparation of the post space

Left: The root canal is prepared to conform to the thickness of the post. The selected length of the post is observed during post space preparation by using the length measurement guide on the preparation instrument.

Right: Immediately before cementation, the surface of the root canal is roughened rotating a diamond-coated bur five times to improve retention. The canal is then irrigated, dried, and, if necessary, chemically conditioned for cementation.

36.3 Post insertion

Left: The head of the post should rest securely on the flat surface prepared as above and exhibit friction even without cementing. Despite sandblasting, posts can be pretreated with a tribochemical coating if required. Only the post itself is coated with the cement, not the root canal. Then the post is inserted with a pumping motion to permit outflow of any excess cement.

Middle: The positioning of the post is controlled radiographically.

Right: Crown base build-up. The retentive head is built up with acrylic resin.

Custom-cast Post-and-core Build-up

Custom-cast posts are indicated when very little coronal tooth substance remains and the tooth will experience heavy loads with the planned comprehensive prosthetic reconstruction. In particular, bridge abutments and terminal abutments of telescopic prostheses are subjected to horizontal and rotational force vectors. To ensure long-term functionality, the post-and-core build-ups must exhibit flexibility and resistance to breakage by protecting the tooth against rotational forces (Pfeiffer et al., 2004, 2006).

In addition, it is important that the shape of the custom-cast post should be congruent with that of the prepared root canal.

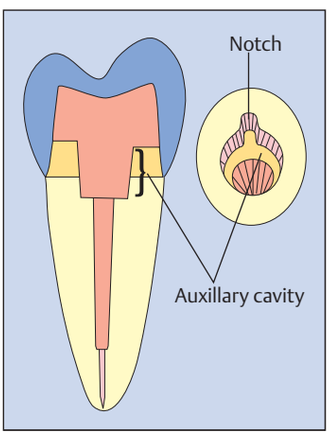
For a good fit and to prevent corrosion, high gold alloys have proved effective. The post and core may be cast as a single unit or fabricated separately. Custom-cast post build-ups can be definitively shaped either directly in the mouth or indirectly on a stone model. For the single-cast technique, a prefabricated plastic post is inserted in the root canal and built up coronally with acrylic. The whole assembly is then invested and the acrylic burned out and replaced with the definitive metal core. Alternatively, the coronal segment can be built up by casting onto a prefabricated post made of a noble metal alloy (the so-called cast-on).

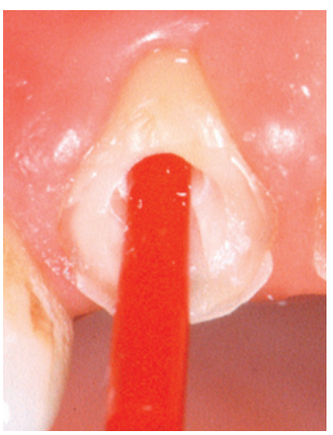
36.4 Post space and auxiliary cavity preparation followed by unit post-and-core build-up

Left: The heaviest loading occurs at the transition between the post and the build-up. The auxiliary cavity preparation on the cavity floor strengthens the post, and the notch prevents any torsion.

Middle: A plastic post (ER System, Komet) is placed into the canal and the core is added with acrylic. Direct preparation is recommended.

Right: After the core preparation, the build-up is removed and then cast as a single unit.





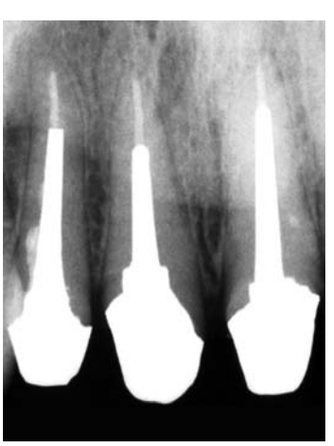
36.5 Casting on

A prefabricated post made of a noble alloy, e.g., Permador, Heraplat or platinum-iridium (ER System, Komet, Lemgo, Germany) is inserted within the canal and the core built up. The build-up is then cast using a noble alloy, directly onto the prefabricated post.

36.6 Insertion of the cast post and core

The canals are cleaned and roughened with a diamond bur, irrigated, and dried. Following cementation, the rough surface of build-ups is seen.

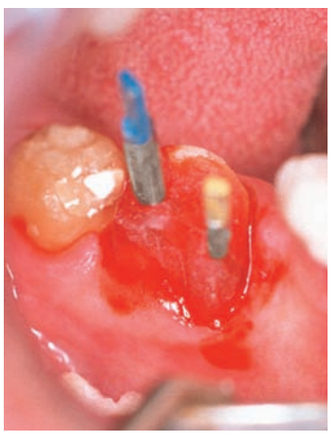
Right: Radiograph showing the correct placement of the custom-cast posts.



Two- or More-piece Post-and-core Build-ups

The use of post-and-core units that are separate build-ups can accommodate any variations in the direction of insertion of the post between the canal and the auxiliary cavity of anterior teeth. These post-and-core units are most often used in posterior teeth with several canals in order to insert more posts and to take advantage of a higher level of retention and optimum retentive protection. They are indicated in cases of extensive coronal destruction, danger of fracture in the furcation area, or limited dimensionality of each individual post. Using the dowel-lock method, the individual post is connected to the built-up restoration, so that it cannot be dislodged after insertion and cementation.

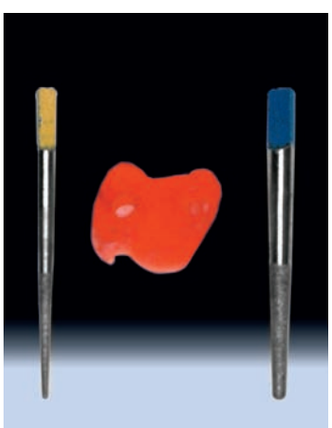
For a separate dowel, a prefabricated titanium post with a smooth shaft is used. Such posts exhibit high resistance to bending, but cannot be cast on. Casting on titanium causes alteration of the crystal structure of the metal and can lead to breakage of the post. Before casting, each separate dowel is removed from the model and subsequently reinserted. In the case of post-and-core build-ups with several posts, one post may be included in the casting with the build-up, but the other dowels must be separated from the build-up.



36.7 Separate post build-up using two posts

Left: Molar with destruction coronally down to the furcation area.

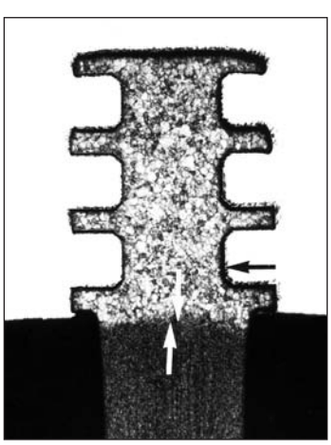
Right: The post space preparation extends in both the distal and mesiobuccal root canals. The coronal build-up is made of burn-out acrylic using two titanium shaft posts of the ER System (Komet, Lemgo, Germany).



36.8 Separate post build-up using two posts

Left: Both posts were removed from the model and only the coronal build-up was casted.

Right: Afterward, the dowels can be repositioned and locked into the cast.



36.9 Separate post build-up using two posts

Left: Before cementation the posts are shortened. In a single clinical procedure, first the cement-coated casting is inserted then both of the cement-coated posts are carefully inserted into the root canals allowing the surplus of cement to flow out. The shafts of the posts are then adapted to the casted core.

Right: Alteration of the crystal structure in the head of a titanium post following casting with a gold alloy (white arrow), as well as a separating oxide layer between the titanium and the casted alloy (black arrow).

37 Adhesive-retained, Fiber-reinforced Composite Posts

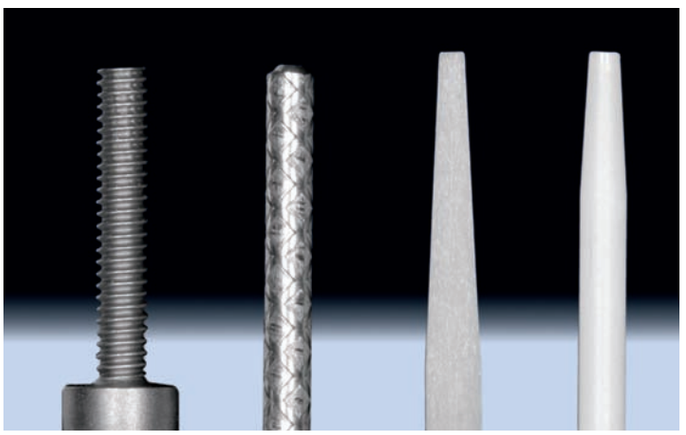
Numerous options of adhesive build-ups are available today, which dispense with the need for root canal posts and which are preferable because they are less invasive (Creugers et al., 2005). Nevertheless, in clinical situations where there is insufficient coronal hard tissue to support the adhesive build-up, root canal pins/posts still provide the only long-term possibility of retention and stability of the build-up.

From the vast array of commercially available post systems and shapes, the conical, passive posts have received an increased level of attention because of the similarity between their shape and the root's shape (Morgano and Brackett, 1999).

It has been shown that in combination with appropriate adhesive systems, the retention of conical posts is significantly improved and passive fitting avoids active loading of the canal walls (Boschian Pest et al., 2006; Dietschi et al., 2006).

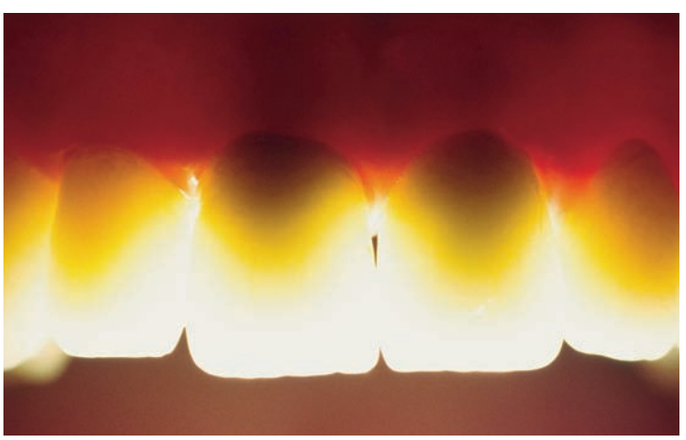
37.1 Range of available materials

Various systems and materials for root canal posts (from left to right): active, threaded cylindrical titanium post; passive titanium cylindrical post with surface roughening, passive glass-fiber-reinforced tapered post made of composite resin, with a smooth surface; and a cylindrical-tapered post of zirconium oxide ceramic, with a smooth surface.



37.2 Light transmission

Transmitted light image of full ceramic crowns, some of which were fixed to metal endodontic post build-ups (central incisors). The metal posts are seen to cause marked inhibition of light transmission and shadows in the area of the crowns and the surrounding soft tissues.



37.3 Post systems and geometries

Advantages and disadvantages of various post systems and post geometries. Active root canal posts are also available in various shapes and sizes.

	Active post systems	Passive post systems		
	Threaded posts	Tapered	Cylindrical	Cylindrical-tapered
Advantages	• Most retentive • Time-saving	• Shape similar to the root • Less apical substance loss • Good clinical success rate	• Good retention • Even distribution of stress • Good clinical success rate	• Good retention • Minimal apical substance loss
Disadvantages	• High risk of root fracture • High clinical failure rate • High substance loss	• Less retention • Uneven stress distribution • Risk of root fracture	• Greater apical substance loss • Higher risk of perforation	• Uneven distribution of stress

The ongoing discussion concerning the corrosive characteristics and the biomechanical behavior of root canal posts, as well as the altered optical requirements with regard to the increasing use of metal-free restorations, has led to the introduction and use of posts made of ceramic materials or fiber-reinforced composite resin, alongside traditional metal root canal posts (Arvidson and Wróblewski, 1978).

For root canal posts based on reinforced composite materials, the basic material is an epoxy resin reinforced by carbon or glass fibers. These materials demonstrate mechanical characteristics similar to dentin and can in certain circumstances be relatively easily removed (Lassila, 2004). In vitro investigations have indicated that use of these posts is associated with a less destructive failure mode in comparison to posts made from other materials (Fokkinga, 2004). If these laboratory observations were corroborated by clinical studies, the fact that a fiber-reinforced composite post is relatively easy to remove would allow uncomplicated retreatment of a tooth after post fracture.

So far, posts made of fiber-reinforced composite material exhibit low radiopacity. In addition, the quality of the post can vary considerably depending on the manufacturer (Grandini, 2005).

37.4 Removal of a glass fiber post

Left: During the removal of a glass fiber post (here: experimental ex vivo situation), it is advantageous to first create a plateau to stabilize the small round bur used to create a point of access in the middle of the fractured post.

Right: For the actual post removal, special carbon-steel burs with a cutting tip are used intermittently at a low speed (800–2000 rpm) with water cooling.

37.5 Radiopacity

Periapical radiograph of maxillary second molar following instrumentation and temporary insertion of glass-fiber-reinforced composite post for length determination. The post is less radiopaque than the remaining gutta percha portion of the root canal filling, which is left in place for apical sealing.

Use of a highly radiopaque adhesive material for final placement of the post can significantly enhance radiographic visibility.

	Metal	Zirconium oxide ceramic	Fiber-reinforced composite
Advantages	• Wide range of systems available • Long-term clinical experience reported	• White color • Translucency • Biocompatibility • High stability	• Favorable biomechanics • Removable, when necessary • Biocompatible • Optical characteristics (with glass-fiber reinforcement)
Disadvantages	• Corrosion problems • High modulus of elasticity • Unfavorable optical characteristics • Destructive failure mode	• Extremely high modulus of elasticity • Extreme hardness • Not removable • Insufficient long-term clinical experience	• Low radiopacity • Anisotropic behavior • Flexible build-up • Coefficient of thermal expansion is different from that of the tooth hard tissues • Insufficient long-term clinical experience

37.6 Materials for root canal posts

Advantages and disadvantages of various materials used for root canal posts.

Creating Post Space and Preparation

In general, following the primary treatment (excavation, endodontic therapy), it is prudent to carry out a defect-based preparation of the tooth so that the final restoration can be designed specifically for each tooth. This procedure provides a better estimate of the vertical extent and the thickness of the remaining tooth structure as well as the biological width.

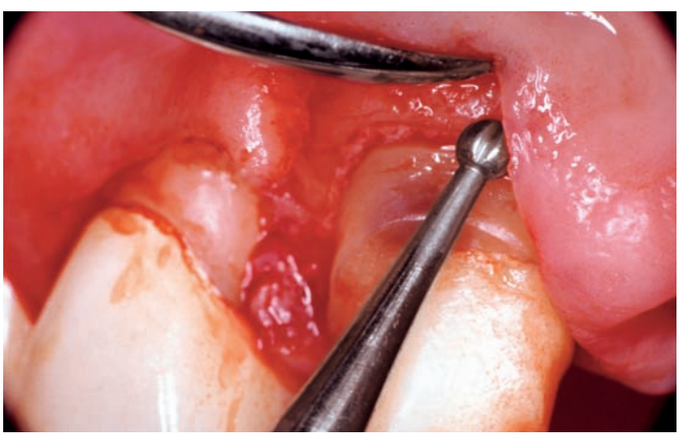
It is generally accepted that the fracture resistance of endodontically treated teeth is significantly affected by the amount of the remaining coronal tooth structure (Creugers et al., 2005; Pereira et al., 2006). The stability of teeth with post-and-core restorations is increased if a dentin collar at least 2-mm wide is prepared apical to the build-up, which is enclosed by the final restoration circumferentially. This preparation, also referred to as the "ferrule" preparation, has a stabilizing effect on the root, and enhances the long-term clinical success of the final restoration (Torbjorner and Fransson, 2004; Pereira et al., 2006).

If the anatomic considerations do not permit this approach, the requirements can be fulfilled by periodontal surgical crown lengthening or orthodontic extrusion, if the root length is sufficient.

Even though endodontically treated teeth have a good clinical long-term prognosis, the possible negative consequences of dental implants should be taken into consideration before such methods involving bone reduction are used in esthetic areas of the mouth (Holm-Pedersen et al., 2007).

37.7 Biologic width

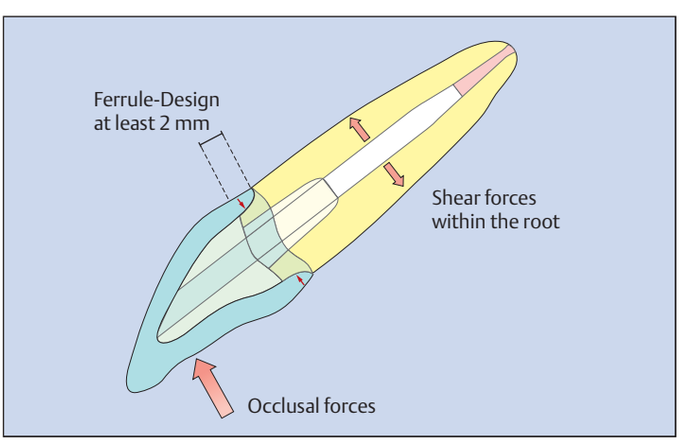
Surgical crown lengthening procedure to create adequate biologic width on a tooth that had been restored using a metal-free post build-up. Without this surgical procedure it would not have been possible to achieve sufficient circumferential marginal adaptation of the subsequent restoration. However, when periodontal procedures that involve removal of bone are undertaken, the clinician must take into consideration the fact that future insertion of a dental implant in this region may be necessary.



37.8 Ferrule effect (as described by Morgano and Brackett)

This effect is caused by almost parallel walls of intact tooth structure apical to the build-up. The definitive crown surrounds this at least 2-mm-wide dentin boundary in a circular fashion, thus absorbing the shearing forces that are exerted on the root by the occlusal forces. With increasing vertical depth of the ferrule the stability of the tooth increases. At the same time, the influence of the material characteristics of the build-up on the stability is reduced.

Right: Clinical appearance of a build-up for a maxillary anterior tooth.



During instrumentation of the root canal for a fiber-reinforced post, one should strive to attain a consistent thickness of the root canal walls, and to remove any residual root canal filling material to the full working length. Taking into consideration the anatomic characteristics of root canal anatomy, the instrumentation working length should at least equal that of the planned crown length. In vitro studies have demonstrated that fiber-reinforced composite posts with deeper canal penetration, in contrast to those with less instrumentation depth, exhibit more favorable stress distribution and a higher level of retention (Boschian Pest et al., 2006; Braga et al., 2006).

In light of these facts, it seems reasonable — even with adhesive restorations — to extend the instrumented working length as far as the root canal anatomy allows, so that the remaining apical seal that is formed by the root canal filling is at least 4–5 mm in length (Goodacre and Spolnik, 1995).

Basically, the procedure for the preparation requires differentiating between direct and indirect post-retained build-ups. Directly prepared post build-ups have the advantage of saving clinical time and sealing the root canal against any bacterial contamination directly following instrumentation. With the indirect technique, for example, fiber-reinforced posts with individual build-ups of ceramic materials can be combined, and this provides high color and form stability.

For cementation of a temporary restoration within the root canal following definitive instrumentation, eugenol-free temporary cements should be used (Chieffi et al., 2006). A significant disadvantage as opposed to the direct procedure, is an enhanced risk of contamination of the root canal as well as mechanical damage to the internal root canal surface during the temporary treatment phase (Saunders and Saunders, 1994). Finally, the indirect procedure requires more invasive preparation because undercuts must be eliminated. In a direct procedure, these could be used as additional retention surfaces.

37.9 Indirect procedure

Left: During root canal instrumentation in anterior teeth one should strive to achieve the greatest length of the fiber post. This increases retention and also provides a more favorable distribution of load.

Right: The glass-fiber post is prepared for impression with a polyether material in a double-mix procedure. For additional retention, a spherical build-up of low-viscosity composite resin is attached at the coronal end.

37.10 Indirect procedure

Left: In the dental technical laboratory, an individual build-up has been created in wax on the fiber post and is subsequently pressed in glass ceramic (lithium disilicate).

Right: The glass ceramic build-up has been fabricated as a separate post build-up and remains separate until the time of final adhesive insertion.

Adhesive Insertion of Fiber-reinforced Posts

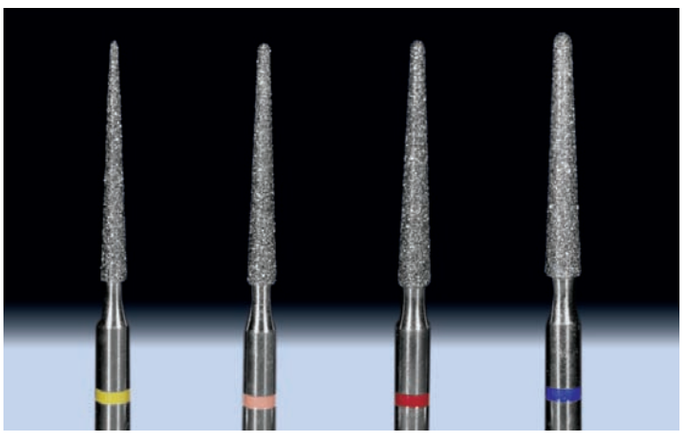
Fiber-reinforced composite posts should be cemented exclusively with an adhesive luting system. During this procedure, it must be kept in mind that the dentin on the walls of the root canal is "hydrophilic" and the post, which is formed from a mixture of epoxy resin and minerals, is "hydrophobic." The scientific literature contains some contradictory recommendations regarding appropriate methods for conditioning root canals and posts.

Conditioning of the Root Canal

Even though multilayered adhesive systems continue to represent the gold standard for the creation of a reliable dentin bond, in recent years, self-adhesive materials have been introduced that achieve remarkable adhesion (Vichi et al., 2002; Bitter et al., 2006; Wrbas et al., 2006). Considering the wide product range and innovative systems on the market, it is recommended to use clinically proven adhesive systems if any doubts persist in the clinician's mind.

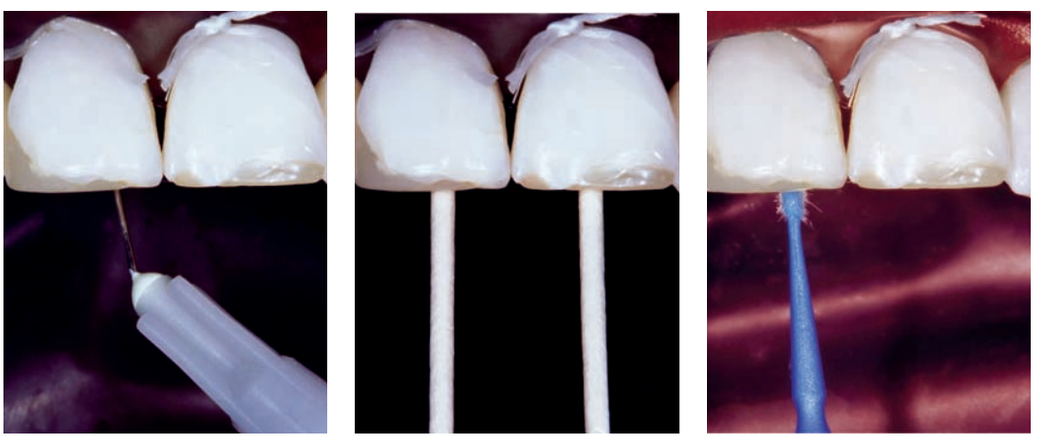
An additional increase in retention of the root canal post can also be achieved with adhesive systems by roughening the canal wall using shape-congruent diamond instruments (Nergiz et al., 1997; Balbosh et al., 2005). A sterile isotonic saline solution (0.9%) is suitable for irrigating the canal before positioning the post with an adhesive coating, or following acid conditioning of the root canal. Increasingly, sodium hypochlorite (up to 5.25%) is used as a irrigating solution in combination with the adhesive (Muniz and Mathias, 2005).

Finally, the root canal can be dried using sterile paper points.



37.11 Roughening the root canal wall

Diamond-coated burs can be used to increase retention of the post by roughening the root canal walls. The different sizes of the burs are congruent in shape with the different sizes of the glass-fiber posts and are applied manually.



37.12 Irrigating, drying, conditioning

Left: Isotonic saline solution has proved to be an efficient irrigating medium.

Middle: Subsequently the instrumented canal is dried using sterile paper points. Paper points can also be used to remove excess material when using multistep adhesive systems.

Right: Special brushes are used for the application of adhesive components within the canal.

While a greater layer thickness of the luting material has no negative effect on the bonding to root canal wall dentin, eugenol sealers in existing root canal fillings exert a negative effect on the bond (Muniz and Mathias, 2005; Perez et al., 2006). When adhesive fixation is planned, sealers based on epoxy resin should be used for endodontic treatment, and the use of eugenol-free temporary retentive materials for indirect fabrication of posts (Chieffi et al., 2006).

For the application of adhesive agents within the root canal, special minibrushes appropriate to the canal geometry are indicated. Sterile paper points should be used for the removal of any excess adhesive material.

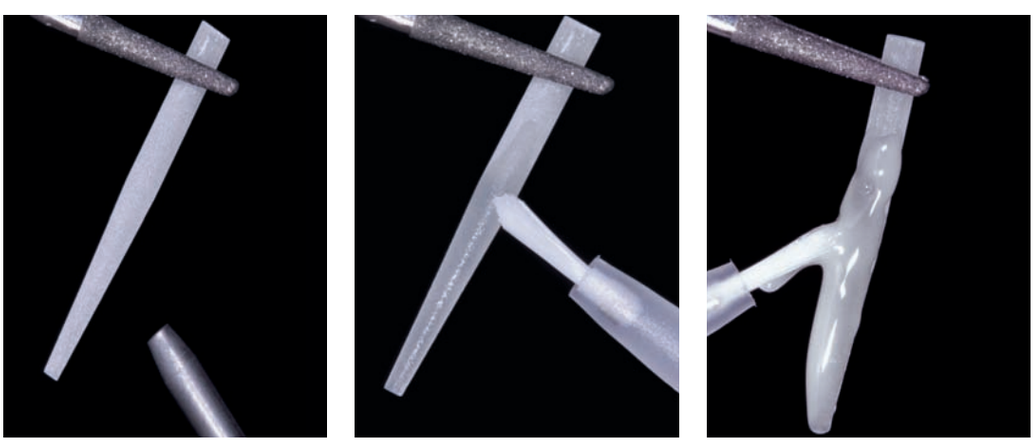
Conditioning of the Post Surface

Along with adhering to dentin, there must also be a stable bond between the luting material and the surface of the fiber-reinforced post. In most cases, "conditioning" of the post surface is required.

The literature is conflicting regarding the efficiency of various conditioning procedures. (Perdigao et al., 2006; Magni et al., 2007). However, very good adhesive characteristics were demonstrated with corundum treatment of the post surface, or through a tribochemical silicatization with subsequent silanization (Balbosh and Kern, 2006; Schmitter et al., 2006). "Chairside" conditioning of the post surface using these methods is, however, time consuming, and is accompanied by the risk of introducing errors during the individual steps of the clinical process. Because of these difficulties, some manufacturers now provide prefabricated and coated glass-fiber posts (Edelhoff et al., 2006).

37.13 Prefabricated posts

Silicoating and silanization of the upper glass-fiber post has been carried out by the manufacturer together with the addition of a final layering of a protective varnish. The lower glass-fiber post is not coated. After try-in, the clinician must simply clean the prefabricated coated post with alcohol and apply the adhesive luting material.



37.14 Chairside conditioning of the post surface

An efficient method to achieve a stable bond to uncoated posts involves tribochemical silicoation via air-blasting with a pressure of 1 bar and a grain size of 30 µm (left: Rocatec System, 3M ESPE, Seefeld, Germany). Subsequently the silicoated post surface is silanized (middle) and a low-viscosity resin cement is applied (right).

Positioning the Post

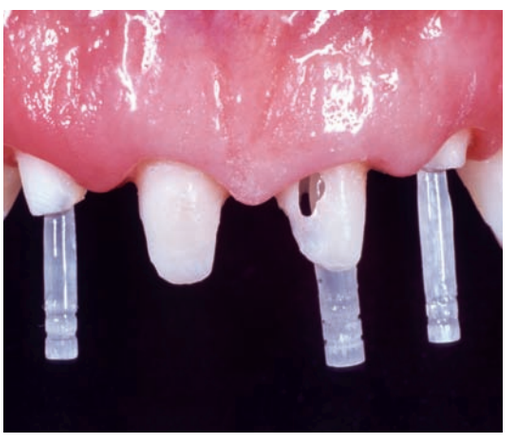
Light conduction through glass-fiber posts is limited and is influenced by the post geometry (Patyk et al., 2005). Therefore, the prerequisite of sufficient polymerization of a purely light-curing bonding agent is not guaranteed for all of the usual post lengths (Patyk et al., 2005).

In order to achieve a clinically acceptable degree of polymerization, it is necessary to use curing or dual-curing adhesive materials. Because of the often quite limited handling times for such systems, in particular cases the sole application of the adhesive material onto the prefabricated root canal post is recommended.

37.15 Initial clinical situation and build-up

Left: Patient with anterior maxillary tooth trauma. All anterior teeth except the left lateral incisor had been endodontically treated before the trauma occurred. The low fracture line required a limited crown lengthening procedure on the palatal aspect.

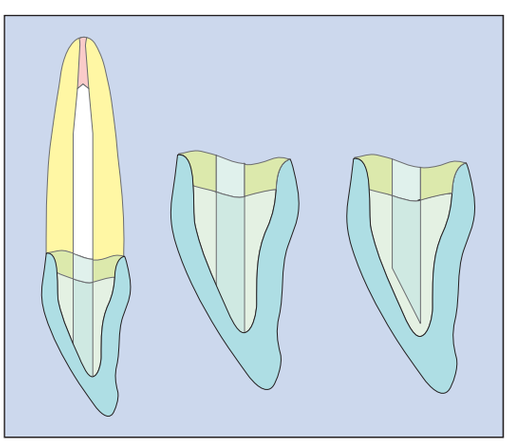
Right: Because of only minimal destruction, the maxillary right central incisor was able to be built up directly with a dual-cure adhesive composite system. All other anterior teeth received coated glass-fiber posts.



37.16 Direct build-up

Left: Following adhesive placement of the post, the exposed portions of the post were coated with a thin layer of low-viscosity composite resin and finally built up using a highly filled composite.

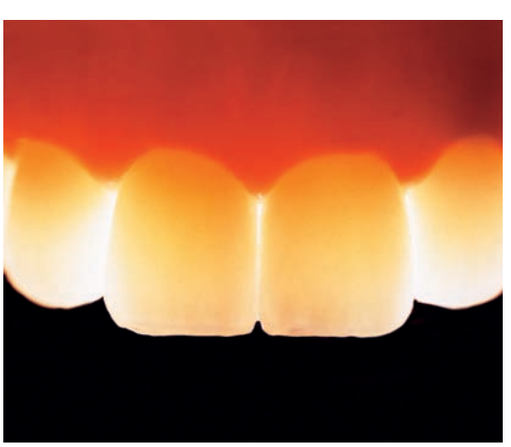
Right: If the post protrudes from the composite build-up, this can lead to stress concentration between the post and the inner surface of the crown. In addition, the capillary effect is increased, which accelerates hydrolytic degradation. This can be avoided by enveloping the entire post with low-viscosity composite.



37.17 Crowns

Left: The four glass-ceramic crowns (C.D.T. Oliver Brix, Wiesbaden, Germany) were inserted using a dual-cure adhesive composite system. Before crown placement, the composite portions of the build-ups were roughened and silanized.

Right: Due to the high translucence of the glass-ceramic crowns and the materials used for the build-up, a quite natural transmission of light was achieved.

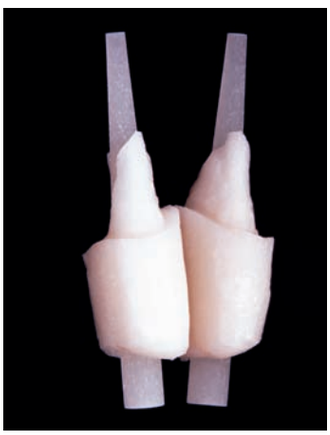


This should prevent premature hardening of the adhesive material within the root canal. This clinical procedure, however, has been associated with an increased risk of void development during the post insertion, the long-term clinical effect of which has not yet been completely clarified (Watzke and Naumann, 2006).

Today, numerous application systems are available that, if efficiently and speedily used, allow void-free direct application of the adhesive agent within the root canal. The use of these newer materials demands a certain level of experience with adhesive systems.

37.18 Indirect procedure: initial situation

A severely discolored acrylic crown on the maxillary right central incisor. Following removal of the crown, the clinical examination revealed extensive secondary caries, which had resulted from the poor marginal seal of the crown. Because of the high level of tooth destruction, the indirect procedure for fabrication of a ceramic build-up was selected.

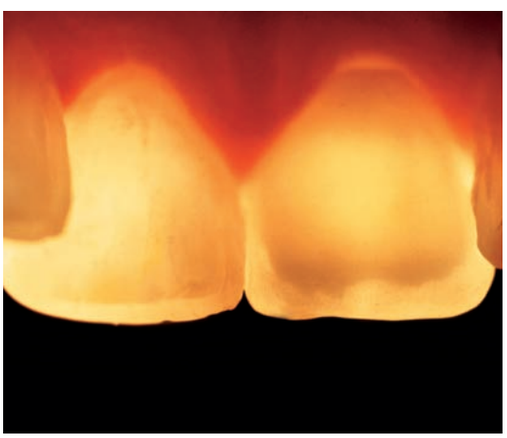


37.19 Indirectly fabricated build-up

Left: The build-up of lithium disilicate, pressed glass-ceramic was prepared separately from the glass-fiber post and remained separate until the time of final adhesive insertion.

Middle: Post try-in. By means of the adhesive insertion, the separate parts of the post build-up were fitted to form an integrated functioning entity.

Right: Finally, the preparation was refined and structured for the subsequent crown.



37.20 Adhesive placement

Left: Following adhesive insertion, the appearance of the glass-ceramic crown is in harmony with the adjacent natural tooth (C.D.T. Rübben, University Clinic, Aachen, Germany). The gingival tissue is inflammation-free, without any dark discoloration.

Right: Thanks to the use of translucent restorative materials, the transmission of light is comparable to the natural tooth structure. The surrounding soft tissues exhibit a natural appearance without any of the dark shadowing effect that is often associated with metal-supported restorative systems.

38 Clinical Methods with Glass-fiber Posts

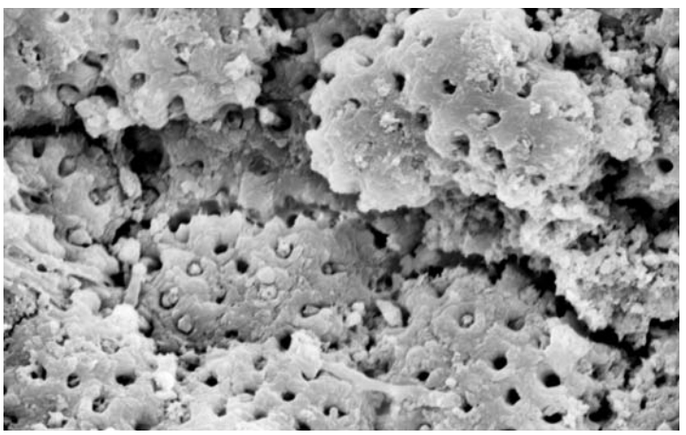
The primary goal of modern dentistry is the preservation of as much natural tooth structure as possible. Nickel titanium (NiTi) instruments are primarily selected to reduce the aggressiveness of hand instruments within the root canal, to maintain normal root canal anatomy, and to standardize root canal instrumentation. NiTi instruments remove a conservative amount of root dentin. When commercially available, preformed drills and/or Largo drills are used a large amount of root canal dentin is removed, enlarging the diameter of the canal. Recently a NiTi instrument (Mtwo, VDW, Munich, Germany) for removing only the gutta-percha during post space preparation has been proposed. This instrument is highly flexible and does not cut laterally, thus preserving the root canal dentin.

The removal of the gutta-percha from the root canal walls must be followed by the use of ultrasonics and EDTA for complete cleansing of the root canal walls of endodontic cement and residual gutta-percha, and to permit surface contact between the luting/adhesive agent and the dentinal walls. The efficacy of this procedure has been recently demonstrated (Coniglio, 2008). The diameter and size of the Mtwo NiTi drills correspond to the smaller-sized fiber posts that are commercially available.

38.1 NiTi preparation

Scanning electron micrograph (SEM) showing part of the dentinal wall after use of Mtwo instruments to remove gutta-percha and sealer, with subsequent use of ultrasonics and EDTA. Most of the dentinal tubules are open and clean.

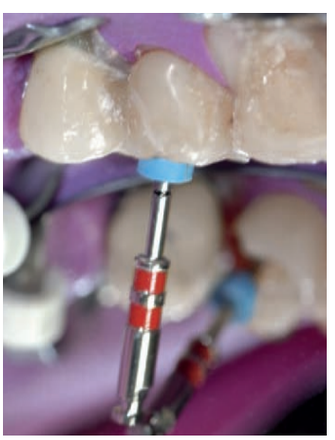
Right: The Mtwo NiTi file is highly flexible.



38.2 Post space preparation

A premolar after post space preparation.

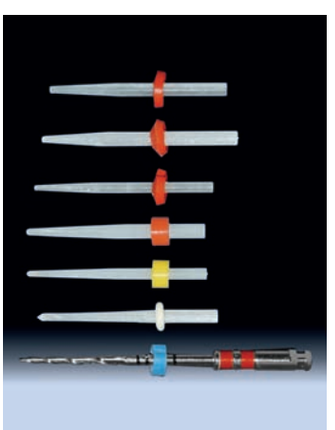
Right: The Mtwo instrument is inserted into the root canal preparation and the working length is assessed.



38.3 Selection of the glass-fiber post

The smallest fiber post is inserted and the working length is measured.

Right: The working length of the Mtwo drill compared with the smallest GC fiber posts available (DT Light Post, RTD; FRC Postec Plus, Ivioclar-Vivadent; Unicem posts, 3MESPE).



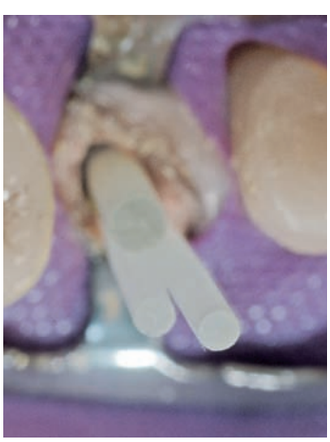
Lateral Compaction Fiber-post Technique

The use of fiber posts is a treatment intended to conserve remaining tooth structure. A frequently used procedure, the fiber-post technique is followed by a choice of various therapeutic options, and many factors have to be taken into consideration in order to optimize mechanical properties, esthetics, and longevity.

The main causes of failure of restorations retained with fiber posts include caries, loss of retention of the post or the crown, root fracture, post distortion, and post fracture (Lewis, 1998). Frequently, failures are related to the mechanical properties of the posts. The use of rotary NiTi instruments results in canals with small diameters, especially at the coronal aspect, which reduces the risk of root fracture and perforations. The clinician may select a single post of appropriate dimension, shape, and material, or use multiple smaller posts. Not infrequently, the clinician will have to use special anatomic posts, which require more time to fit and are more expensive.

38.4 Glass-fiber post as framework for the build-up

Lateral compaction of the fiber post is carried out with 0.5 DT Light posts at the try-in stage and after abutment preparation.



38.5 Multiple glass-fiber posts

The clinical steps of a build-up procedure using the lateral compaction fiber-post technique for restoring a canine are shown.

38.6 Lateral compaction with multiple fiber posts

In the root canal of a premolar, different combinations of fiber posts are tried-in.

A good fit is best achieved with a thin and uniform layer of cement on all canal walls. Variations in cement film thickness along the fiber post can result in nonuniform stress distribution throughout the root, which can increase the failure rate (Kuttler, 2000). Clinical studies have shown that the most common cause of failure of fiber posts is not root fracture but debonding (Fredriksson, 1998; Ferrari, 2000), which probably occurs in the absence of the ferrule restoration or in the presence of excess cement, especially at the coronal aspect.

Depending on the root anatomy and shape of the post preparation space, numerous commercially available posts have been used, but their adaptation to the root canal anatomy is not always ideal. A new brand of smaller posts of different sizes has been developed, however, they are not indicated for single-post restorations.

Several recent laboratory investigations (Porciani et al., 2006) have shown that in most prepared root canal spaces, multiple fiber-post placement was necessary, especially with in oval root canals. In such cases, a modification of the lateral compaction technique is recommended, i.e., placement of a master post that effectively fills the apical segment of the instrumented canal, and subsequent placement of additional thinner posts that permit use of the lateral compaction technique to fill the middle and coronal thirds of the root canal, where it is wider and often more oval than in the apical third. SEM observations have revealed that this technique considerably reduces the thickness of the filling materials in both circular and oval sections of root canals. Also, a fracture resistance test has shown how different combinations of thinner posts (such as DT Light Post, RTD, St. Egère, France) are able to withstand loading forces (Duret, 1990).

One recent study focused on the importance of a thin layer of cement in failure prevention, since this may affect the dentin–cement-post interface, which is considered to be the weakest point of the entire complex (Porciani, 2006). This study suggested consideration of combinations of multiple small posts as an alternative to single posts, especially in canals that are not perfectly round.

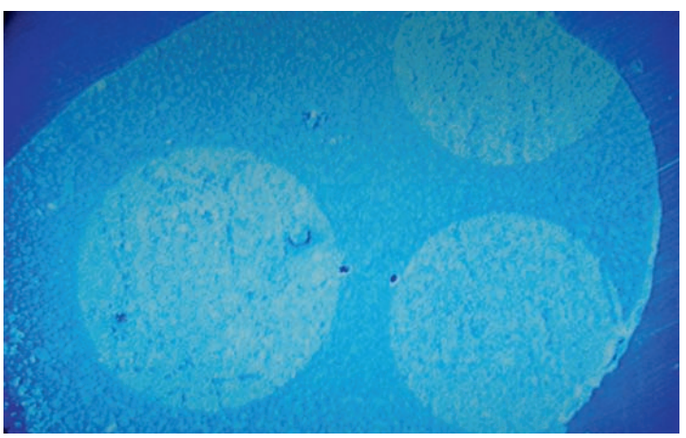
In some cases, it may be prudent to use a single large master post, with smaller accessory posts. The selected combination of posts depends on root canal anatomy, as well as the skill, knowledge, and experience of the clinician.

A clinical study of 50 endodontically treated teeth (premolars, canines, and maxillary incisors) restored using the “lateral condensation fiber-post procedure” and a porcelain crown (all-porcelain and/or porcelain-fused-to-metal) was initiated 1 year ago, and at the most recent recall, no failures had been reported.

38.7 Clinical test: multiple-post technique

Left: The micrograph of a canine shows the good adaptation of the three posts of different sizes and the resin build-up material (low viscosity, Flowdale composite).

Right: The instrumentation is carried out without placing any adhesive onto the root canal dentin, so that following abutment preparation the post can be removed and, using SEM, the integrity of the material combination between the post, seating, and build-up composite can be evaluated.

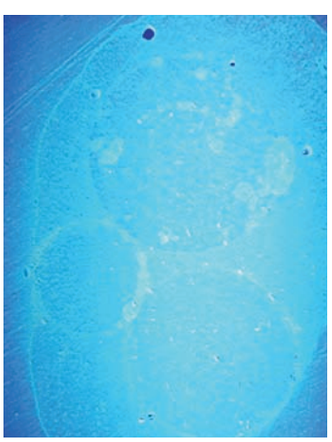


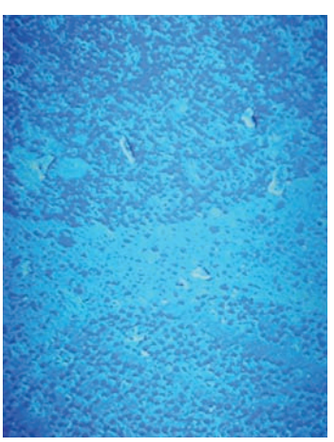
38.8 Microscopic depiction

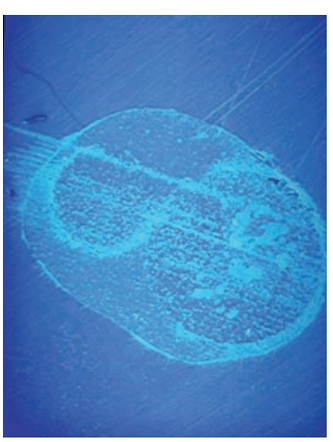
Left: The micrograph shows good adaptation between the resin and the posts in the apical third.

Middle: Higher magnification. The transition between two posts is perfectly achieved by the high wettability and consistency of the Flowdale composite.

Right: Apical segment of the root, where only two posts of different sizes are discernible. The widest post is the master post, while the other is a smaller one used for filling the empty space, reducing the thickness of the luting agent.







39 Endodontic Retreatment Procedures

Good to very good long-term prognosis for initial endodontic treatment has been demonstrated in controlled clinical studies. Retrospective as well as randomized clinical studies have demonstrated healthy periapical conditions after an observation time of 4 or more years in more than 90% of all cases of teeth treated endodontically (Strindberg 1956; Molven et al., 2002; Farzaneh et al., 2003). Periapical periodontitis is a significant factor that influences prognosis. In teeth with periapical disease at the start of retreatment procedures, the Toronto study demonstrated that after 4–6 years, almost 80% of the retreated teeth exhibited a healthy periapical condition (Farzaneh et al., 2004).

On the other hand, epidemiologic studies have shown that the aforementioned good treatment results are only seldom achieved in general dental practice. Overall, 25%–35% of teeth treated endodontically in a general dental practice will have persisting apical periodontitis. The *quality* of the root canal filling was determined to be a criterion that significantly influenced the overall clinical result (De Moor et al., 2000; Kirkevang and Horsted-Bindslev, 2002).

If it is not possible to reduce the level of microbial infection of the complex root canal system to at least below a clinically relevant level, the periradicular lesion will not heal or will only heal incompletely. Common causes of failure of the root canal treatment are: inadequate asepsis, inadequate access cavity preparation, undetected (missed) and therefore unfilled root canals, insufficient instrumentation and root canal filling technique, as well as coronal leakage.

Nonsurgical retreatment remains the treatment of choice in cases of persisting periapical periodontitis. In contrast to a surgical procedure, it offers a minimally invasive approach to the cause of the problem without the danger of damage to adjacent anatomic structures; it is also associated with significantly lower postoperative discomfort for the patient (Friedman, 2002). But even carefully carried out endodontic treatment can end in failure when the extremely complex root canal system can be only partially cleansed and filled three-dimensionally using the treatment techniques currently available.

Additional causes of the persistence of periapical radiolucencies include the so-called extraradicular infections, e.g., *Actinomyces*, foreign-body reactions (e.g., filling materials, presence of cotton fibers, food particles, etc.), infected cysts, or the scarred healing of the periapical tissues (Nair, 2006). In such cases, a microsurgical approach is recommended. On the basis of a meta-analysis, Friedman (1998) demonstrated that surgical root canal therapy in combination with orthograde retreatment led to significantly better results.

If endodontic retreatment is deemed necessary, several — some very complex — factors must be considered during treatment planning. The clinician must have a clear understanding of the etiology and pathology of the periapical lesion, the microbiology, as well as the technical possibilities and limitations of the retreatment procedure. It is important to note that the success of the endodontic retreatment procedure is highly dependent on the degree of training/education of the clinician. As this may be out of the scope of experience and expertise of the general dentist, referral of such cases to a specialist with appropriate experience and knowledge may be appropriate.

No less important is the participation of the patient in the discussion of retreatment possibilities, with all due consideration of the costs and risks.

Decision Criteria

When Should Retreatment be Considered?

If endodontically treated teeth exhibit persisting or acute clinical symptoms, lesions of endodontic origin (Kvist, 2001), or periodontal disease as a result of endodontic problems, retreatment should be considered.

Also restorative problems, such as reinfection of the root canal system because of coronal leakage or the necessity for additional restorative treatment in the face of inadequate root canal therapy, represent indications for endodontic retreatment. On the other hand, orthograde retreatment may be contraindicated if no pathology is present or if the patient is unwilling to accept the risks of retreatment or the higher costs that are often associated with necessary prosthetic retreatment.

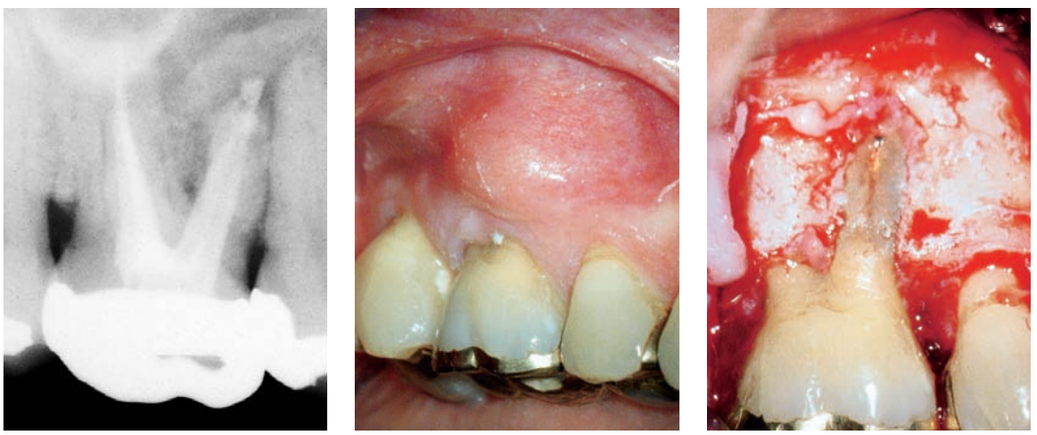
Alternative treatment strategies including consultations with other specialists (prosthodontist, periodontist, implantologist, orthodontist) should be a part of the treatment planning, and should be openly discussed with the patient.

39.1 Clinical symptoms

Left: Acute periradicular abscess extending from the endodontically treated tooth 16.

Middle: Intraorally, there is a buccal swelling.

Right: Combined perio-endo lesion with total destruction of the vestibular bone over the mesiobuccal root.

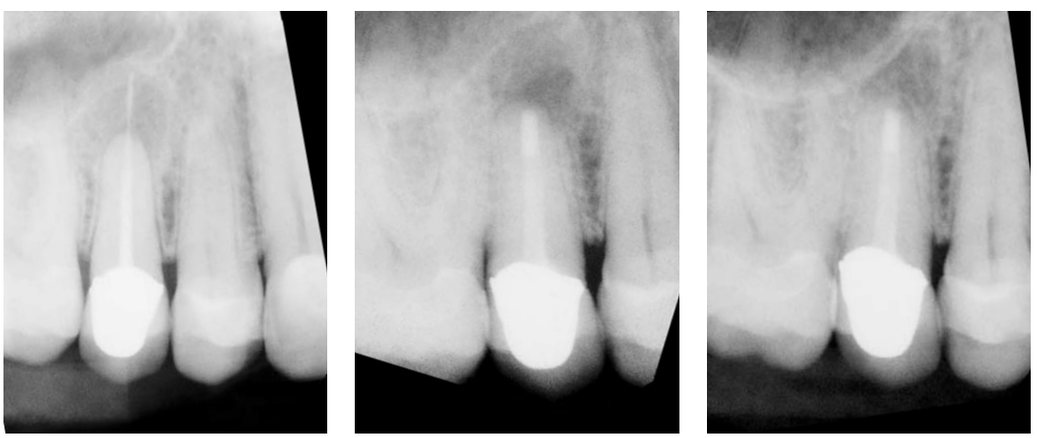


39.2 Lesion of endodontic origin

Left: Extensive lesion of endodontic origin resulting from underfilling of the root canal system and an extruded gutta-percha point.

Middle: Situation following orthograde retreatment with maintenance of the restoration (apical root canal filling with mineral trioxide aggregate [MTA], adhesive build-up with a glass-fiber post and composite, as well as cystectomy).

Right: Six-month follow-up radiograph of the functional and symptom-free tooth, demonstrating apical regeneration.

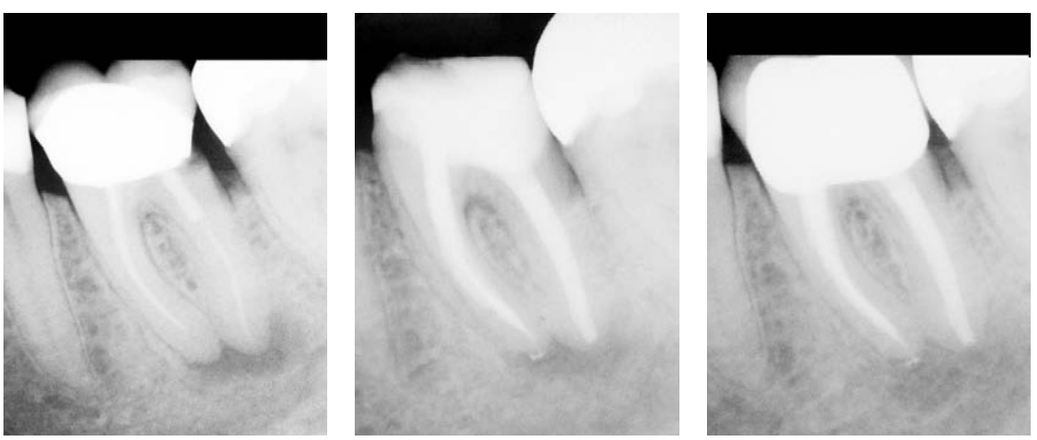


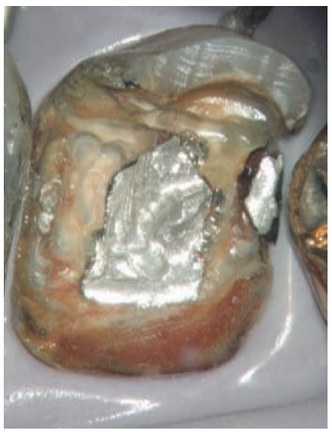
39.3 Coronal leakage

Left: Because of its open margin, the crown on tooth 36 must be replaced. Owing to coronal leakage, the inadequate root-canal filling, and the chronic apical periodontitis, the root canal must be retreated.

Middle: Radiographic view following retreatment, root canal obturation, and adhesive build-up.

Right: Follow-up radiograph taken 6 months later with the new definitive restoration; note the increasing resolution of the periapical radiolucency.

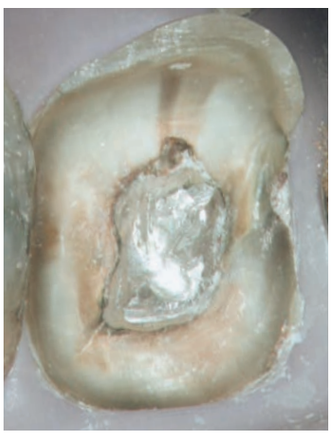


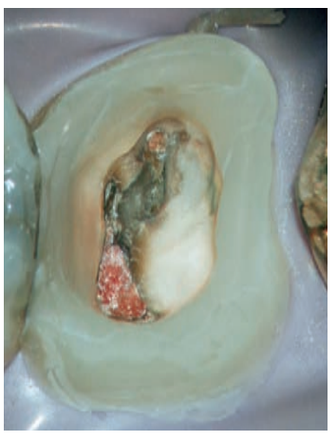


39.4 Deficient restoration as a cause of a lesion of endodontic origin

Left and middle: Endodontic therapy on tooth 26 was carried out 15 years earlier. The patient is free of symptoms but the tooth requires full crown coverage because of the defective amalgam restoration. The obvious apical radiolucency on the radiograph and coronal leakage mean that endodontic retreatment is the indicated procedure.

Right: Clinical view following removal of the majority of the amalgam restoration.





39.5 Preliminary treatment

Left: Complete removal of all secondary caries.

Right: Adhesive composite build-up to prevent bacterial contamination during the stage of dressing the root canal with calcium hydroxide.

39.6 Results

Left: Radiograph immediately following endodontic retreatment and filling.

Right: Six-month recall radiograph reveals complete healing of the apical lesion.

39.7 No retreatment indicated

Underfilled canal system. Teeth 37 and 36 had received partial gold crowns 15 years previously, and showed perfect margins and functional occlusal morphology. The patient was free of clinical symptoms despite a slight widening of the periodontal ligament space on the radiograph.

Left: Underfilled root canals with apical ledge formation. The tooth has served as a bridge abutment for 12 years and the restoration is fully functional. The periodontal ligament space is not widened and the lamina dura is intact.

Timing of Root Canal Therapy

The prevention or the healing of apical periodontitis (AP) as well as the long-term retention of the tooth in a functional and symptom-free condition is the goal of any endodontic treatment. On this basis, endodontic therapy can be termed "successful" when the tooth remains healthy without any radiographic evidence of periapical inflammation or destruction and when there are no clinical symptoms or other signs of inflammation.

On the other hand, a clinical "failure" is characterized by the persisting presence of periradicular inflammation and/or the occurrence of clinical symptoms and signs of inflammation. In this regard, one must differentiate between such cases and those that exhibit typical signs of periapical inflammation but are nevertheless in the healing phase.

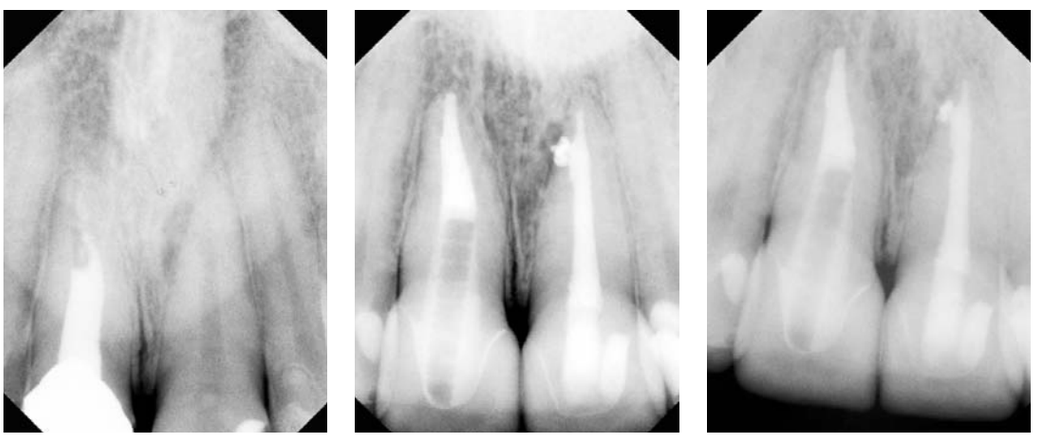
Apical periodontitis can take up to 4 years or more to completely heal, but in 89% of cases radiographic signs of healing can be observed after only 1 year (Orstavik, 1996).

39.8 Healed apical periodontitis

Left: Initial radiograph of teeth 11 and 21, both with incomplete root canal fillings as well as radiographic signs of chronic apical periodontitis (CAP).

Middle: Six months later the lateral lesion on tooth 21 shows signs of healing.

Right: Radiographically intact periapical appearance and freedom from clinical symptoms 3 years later.

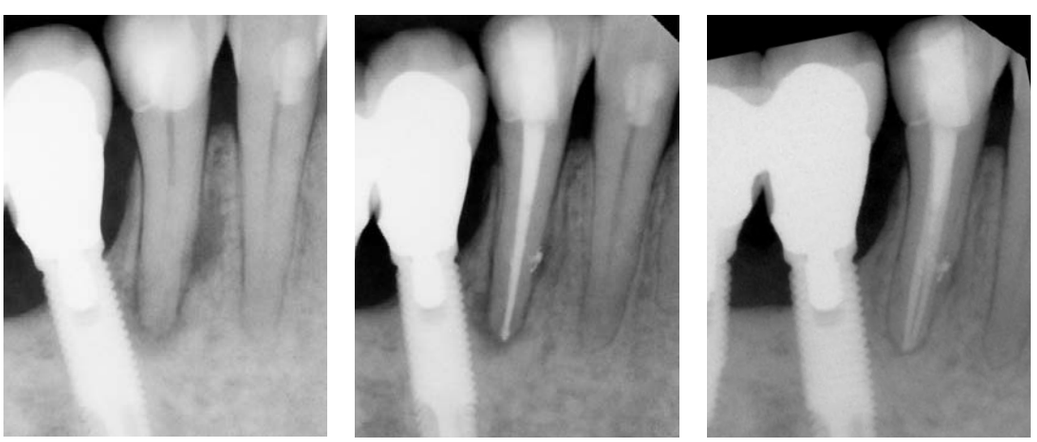


39.9 Healing of apical periodontitis

Left: Lateral and apical lesions of endodontic origin associated with tooth 44.

Middle: Appearance following 4 weeks of a calcium-hydroxide dressing and root-canal filling.

Right: In comparison with the initial situation, 3 months later there is clear evidence of healing, although this is not yet complete.

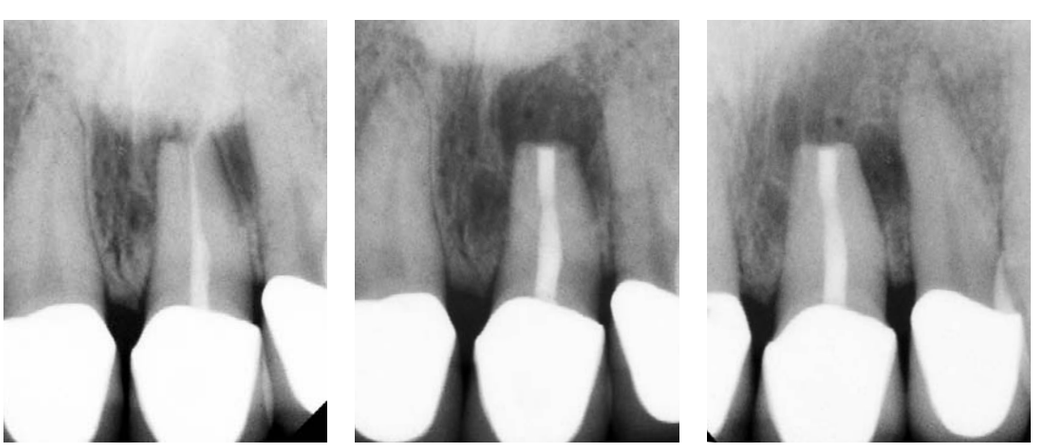


39.10 Persisting apical periodontitis

Left: Tooth 21 exhibits an incompletely filled root canal system and an extensive periapical radiolucency.

Middle: Radiograph following orthograde retreatment, cystectomy and retrograde filling with MTA.

Right: Three years later, the tooth is functional and symptom-free. However, AP is still evident on the radiograph.



Can the Tooth be Saved?

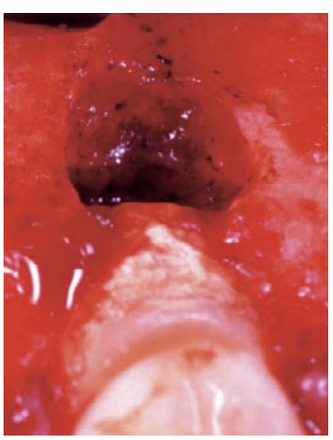
Teeth being considered for endodontic retreatment must be carefully examined with regard to their periodontal integrity. Deep probing depths, mobility, furcation involvement, unfavorable crown–root ratio, bone loss, and mucogingival problems can negatively influence the long-term prognosis of the tooth (Kois, 1996). Teeth requiring endodontic retreatment often exhibit pronounced loss of tooth structure, subgingival caries, or perforations at the level of the alveolar crest.

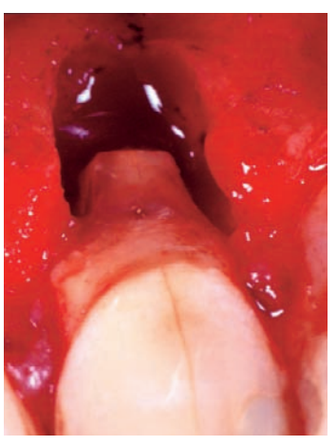
For a good, long-term prognosis of the subsequent prosthetic treatment, sufficient dentin for the "ferrule effect" (Sorensen, 1980) and an intact biologic width must exist (Ross and Garguilo, 1982). In addition, purely endodontic problems such as external root resorption can negatively influence the longevity of any tooth (Heithersay, 2004).

39.11 Combined perio-endo lesion

Left: Initial radiograph of tooth 21 reveals a periapical radiolucency, a partially obliterated root canal system, and a retrograde filling. Probing depths were up to 4 mm.

Right: Radiographic view following orthograde root canal treatment. There is evidence of leakage around the apical amalgam restoration because of penetration of the sealer into the periapical region.

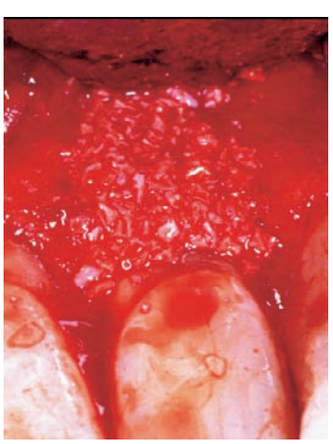


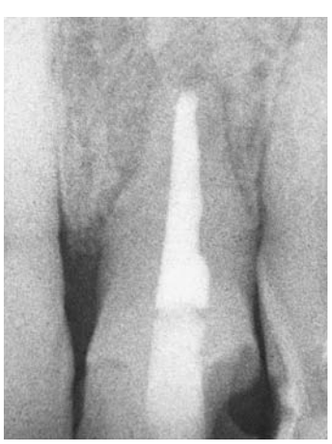


39.12 Periapical lesion of primary endodontic origin and secondary periodontal origin: clinical view of the defect 4 weeks after orthographic retreatment

Left: Surgical view following reflection of a mucoperiosteal flap. The extensive calculus deposits and the periodontal defect are now clearly visible. The diagnosis was a combined perio-endo lesion.

Right: Surgical view following periapical curettage, retrograde root-canal filling with SuperEBA, and cleansing and conditioning of the root surface with citric acid.





39.13 Treatment of periodontal destruction

Left: Guided bone regeneration with Bio-Oss and a membrane (ATRISORB). (Courtesy of Dr. E. Hernichel-Gorbach, MSD.)

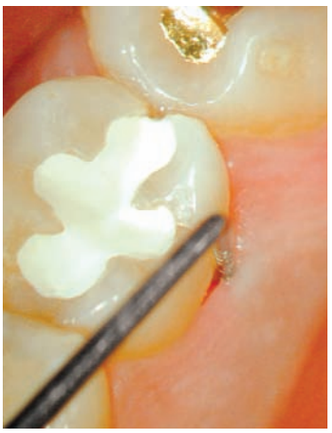
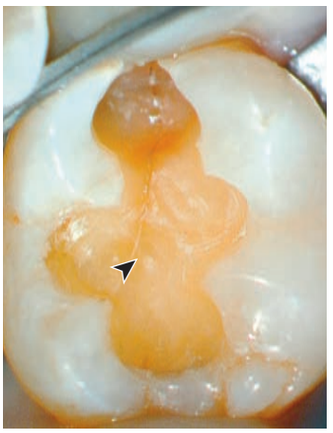
Right: Radiographic view following completion of the retreatment; the prognosis remains uncertain.

39.14 Lesion of primary endodontic and secondary periodontal origin

Left: Initial situation of tooth 47 with pulpal necrosis and chronic apical periodontitis.

Middle: Isolated periodontal defect on the lingual aspect, probing depth 9 mm, and grade 2 furcation involvement. Preliminary diagnosis was a primary endodontic and a secondary periodontal problem.

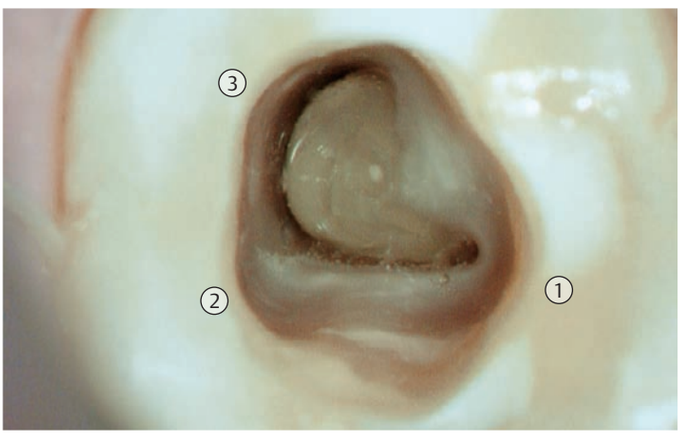
Right: Dentin fracture extending mesiodistal beneath an old restoration (arrow).

39.15 Primary endodontic, secondary periodontal lesion

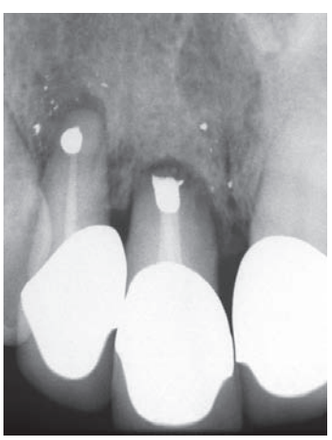
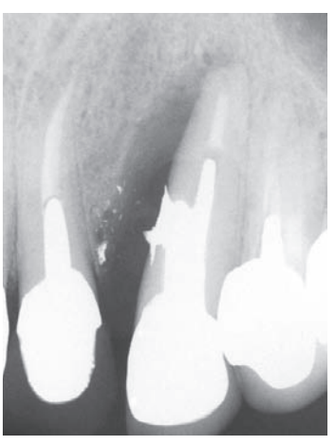
Situation following adhesive build-up restoration and preparation of the access cavity. The so-called C-shaped canal configuration is obvious, with confluence of the mesiobuccal with the distal canal systems (1: mesiolingual; 2: mesiobuccal; 3: distal).

Right: Following completion of treatment. The periodontal situation should be re-evaluated in 2–3 months. The prognosis is guarded because of dentin fracture. Treatment involved a temporary crown.



39.16 Periodontal problem: true combined perio-endo lesion

Because of the extent of the periodontal defects on the two anterior teeth (left) and the canine (right), endodontic retreatment in combination with periodontal therapy is not the indicated treatment here; extraction is recommended.

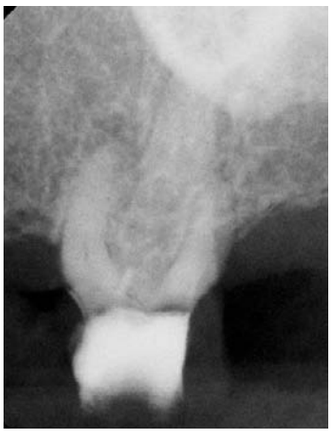



39.17 Periodontal problem: primary endodontic lesion with grade 2 furcation involvement

Left: Initial situation following previous endodontic therapy. Progression of the lesion of endodontic origin into the furcation area and extensive apical root resorption.

Middle: Radiograph following retreatment of the root canals.

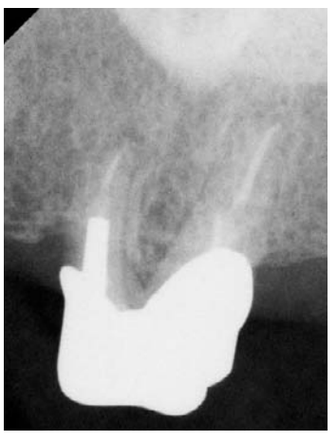
Right: Follow-up radiograph 6 months later. It was not possible to explore the furcation defect with a probe, but there are radiographic signs of osseous regeneration.



39.18 Restorative problems I

Left: The preoperative radiograph of the maxillary molar reveals a severely obliterated root canal and almost complete destruction of the tooth crown itself. Note also the horizontal bone loss.

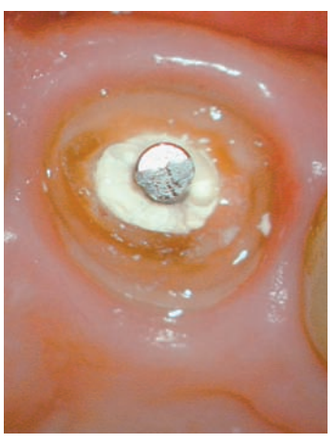
Right: Because of the extensive damage to the hard tissues, this tooth will continue to be at an increased risk of fracture.



39.19 Restorative problems I

Left: The tooth was endodontically retreated despite the patient's advanced age of 87 years and the general medical risks of brittle type 2 diabetes.

Right: One-year follow-up radiograph reveals healing of the AP; the patient was clinically symptom-free. This tooth served as an abutment for a telescopic removable partial denture.



39.20 Restorative problems II

Left: Acute periradicular abscess in relation to tooth 21. Ten years previously the tooth had been endodontically treated. Three years previously it had undergone root resection, and the entire anterior segment had been recently restored. The tooth exhibits an unfavorable crown–root ratio.

Right: Clinical view after removal of the temporarily cemented crown.

39.21 Restorative problems II

Left: Radiographic view immediately following retreatment of the root canal. Because of the large size of the foramen, an apical root filling with MTA was placed and the canal was prepared to receive a post-and-core restoration.

Right: One-year radiographic follow-up. The post does not fill the root canal completely. This tooth is highly susceptible to fracture because of the unfavorable leverage provided by the post as well as the extensive loss of hard tissue.

39.22 Endodontic problems

Left: Tooth 11 fused with a supernumerary tooth exhibiting massive periapical radiolucency. The tooth was treated endodontically 22 years previously, and underwent root resection 3 years previously. Now it was associated with an acute abscess.

Right: Radiographic view following numerous calcium-hydroxide dressings and the apical closure MTA. An attempt to create a periapical barrier using calcium sulfate was only partially successful.

39.23 Endodontic problems

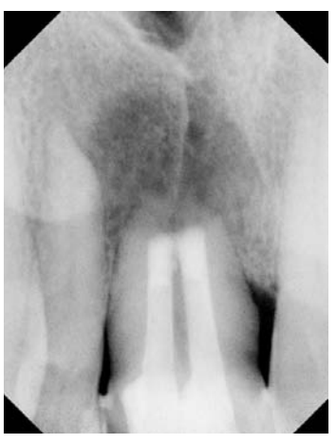
Left: Radiographic follow-up after periapical curettage, correction of the bevel of the resected root surface, and partial removal of the cystic lesion. Histologic examination revealed a radicular cyst. The tooth was subsequently built up using glass-fiber posts and composite resin.

Right: Clinical view following the surgical procedure. An opening was created to allow the cyst to heal.

39.24 Endodontic problems

Left: Seating of the obturator.

Right: The 3-month postoperative radiograph demonstrating progression of osseous regeneration.



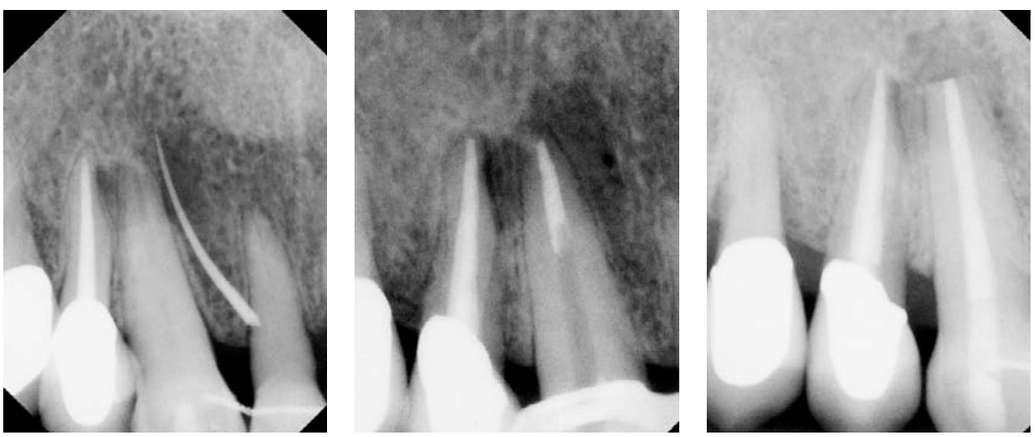
39.25 Endodontic problems

Left: Radiographic check-up 9 months later exhibits further resolution of the osseous defect.

Right: The follow-up examination 2 years later reveals increasing osseous regeneration but not yet complete healing of the lesion. The tooth was symptom-free and functional.

Etiology of Endodontic Failure

Regardless of the initial cause, leakage is the major etiologic factor for endodontic failure (Ruddle, 2002). As part of the framework of diagnosis and treatment planning, the clinician must assess the reasons for failure and also anticipate potential difficulties. Such problems may result from inadequate radiographic diagnosis, inadequate access cavity preparation, perforations, transported apical foramina, instrument fractures, undetected (missed) root canals or underfilled root canal systems, and root fractures or any other extraradicular problems.



39.26 Radiographic diagnosis

Left: Initial radiograph demonstrating the path of a fistula originating from the root tip of nonvital tooth 13. Tooth 14 had been retreated endodontically 3 years previously.

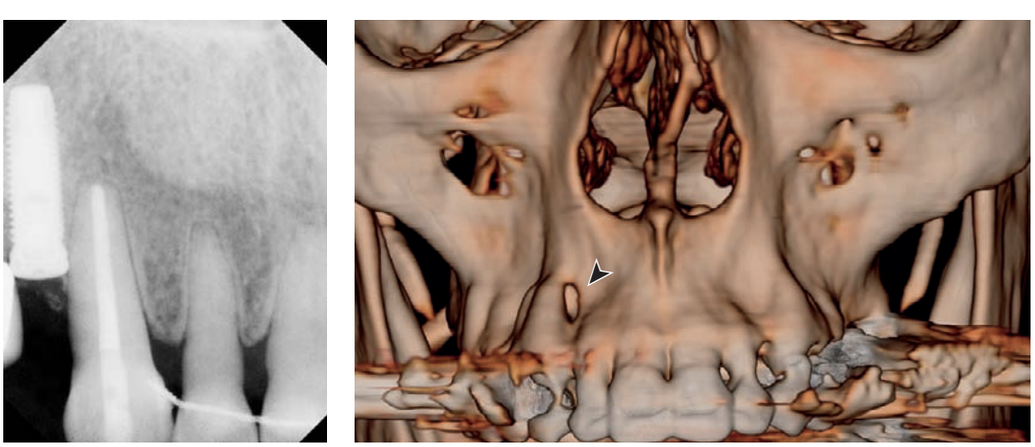
Middle: Radiographic follow-up of the apical root filling of tooth 13.

Right: Tooth 13 was eventually resected, after which the fistula recurred.

39.27 Radiographic diagnosis

The computed tomography (CT) scan reveals an extensive inflammatory lesion with resorption of the palatal cortical bone surrounding tooth 14.

Left: Several weeks following a microsurgical procedure on tooth 13, note the renewed fistula formation (arrow).



39.28 Radiographic diagnosis

3D reconstruction reveals a labial osseous defect over the root tip of tooth 13 (arrow).

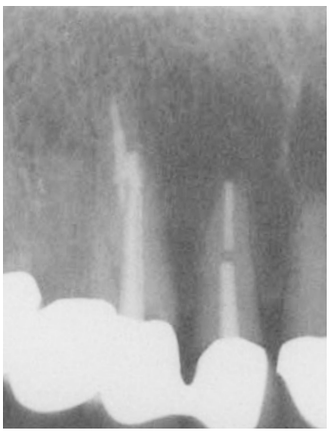
Left: A subsequent surgical procedure revealed a vertical fracture of the palatal root of tooth 14. The radiograph shows the situation following extraction of tooth 14 and placement of a titanium implant. Clinically the implant was inflammation-free and regeneration of the osseous defect was virtually complete.

39.29 Perforation I

Left: Lesions of endodontic origin around teeth 12 and 13. Perforation in the apical segment of the post of tooth 13 was suspected.

Middle: Condition following sealing of the perforation of tooth 13, as well as retrograde root filling of tooth 12 with MTA.

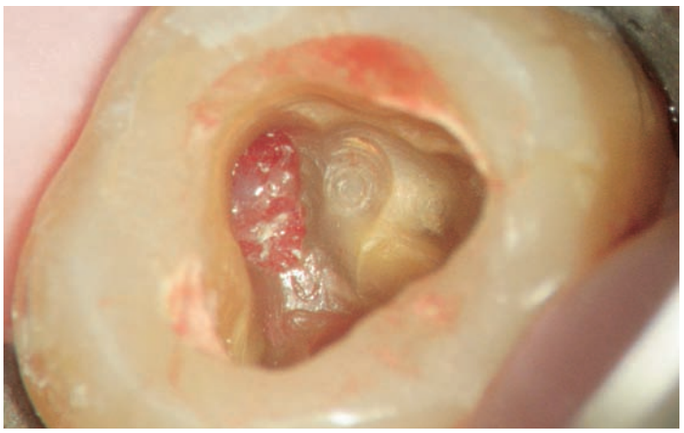
Right: Two-year follow-up radiograph shows an intact periodontium; in addition, there were no clinical symptoms.



39.30 Perforation II

After removal of the temporary restoration, an extensive subgingival perforation was noted distally.

Right: Because of acute apical periodontitis, tooth 27 was treated endodontically as an emergency.



39.31 Access cavity

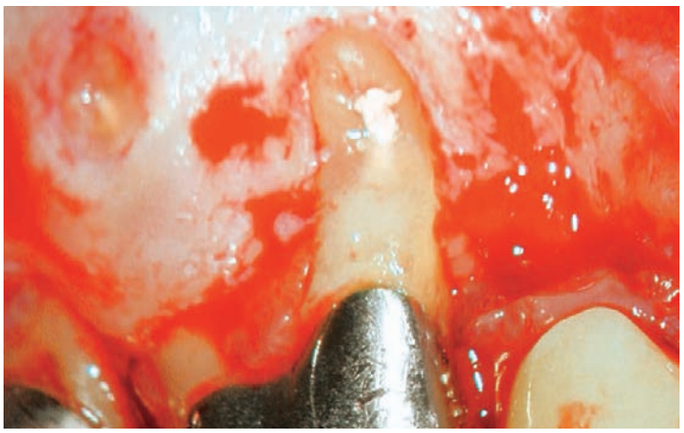
Covering the perforation with calcium sulfate.

Right: Radiographic follow-up after completion of endodontic treatment and placement of an adhesive build-up restoration.

39.32 Strip perforation

The patient had persisting pain following endodontic treatment of tooth 46. The radiograph revealed an underfilled canal system as well as a root canal filling extending almost into the area of the furcation of the mesial canals.

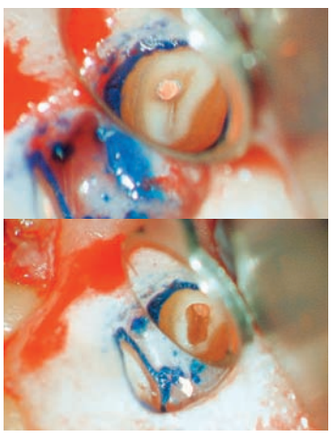
Right: Condition following retreatment of the root canals. Strip perforation of the mesial canal wall was suspected.



39.33 Transported apical foramen

Left: The initial situation showed a severely transported canal system of the mesiobuccal root and suspicion of a perforation.

Right: After reflecting a mucoperiosteal flap, the perforation and a dehiscence of the buccal bone were obvious.



39.34 Transported apical foramen

Left, above: Apicectomy.

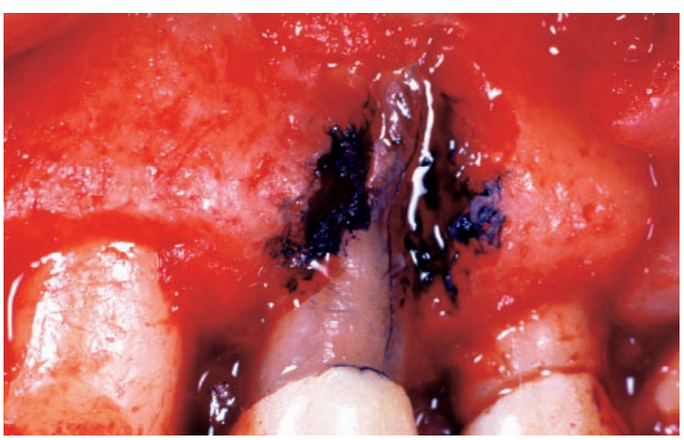
Left, below: Retrograde instrumentation of the mesial canal system.

Right: Radiographic view following completion of retreatment.

39.35 Instrument fracture

Left: Underfilled canal system and a fractured instrument fragment in the mesial root; consequence: CAP.

Right: Image following conclusion of the retreatment. It was not possible to remove the separated instrument fragment, but it was possible to get beyond it and sufficiently fill the canal system.



39.36 Vertical root fracture

Left: Fistula formation despite a qualitatively good root canal filling of tooth 14. The periodontal ligament space appears wider in the coronal third of the root. Periodontal probing depths were within normal range.

Right: Exploratory surgery identified a vertical root fracture on tooth 14. The tooth had to be extracted.

Technical Aspects

Operatory Design

The introduction of the dental microscope, as well as the development of various instruments and tools, has significantly improved treatment results in endodontology, especially in the areas of retreatment and endodontic surgery. These developments have also had a considerable influence on operatory design. For treatment to proceed smoothly, the various instruments must be easily accessible by the dentist and the dental assistant while seated in their operating chairs at the appropriate angle to the patient.

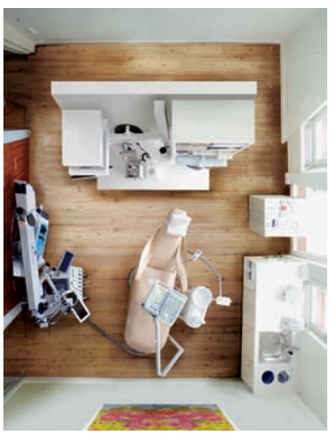
The dental microscope, as well as a special endodontics cart, should be positioned within arm's reach of the clinician. The cart should include all the necessary equipment for the clinician, all of which should be activated via one foot pedal. The x-ray machine should also be located in the immediate vicinity of the clinician, the assistant, and the patient (behind the patient's head), so that radiographs can be taken ergonomically without the necessity for changing the treatment position of the patient, and so that movements of both dental assistant and clinician are reduced to a minimum during the procedure.

39.37 Endodontic operatory I

Left: Bird's eye view of the operatory. All clinical areas are arranged ergonomically.

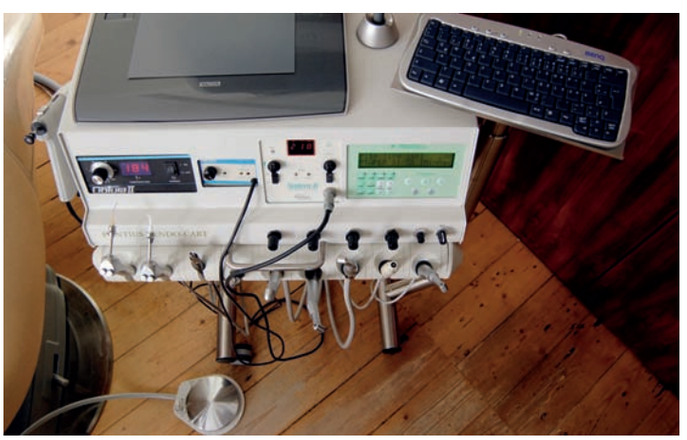
Middle: The behind-the-head cabinet serves as a radiographic barrier and also as a working surface for the dental assistant and the clinician. It is also used for the storage of instruments and materials required, and contains all the necessary equipment for digital data accumulation.

Right: Working area for the clinician.



39.38 The Pontius Endo-Cart (Thomas Dentalgeräte, Breidenbach, Germany)

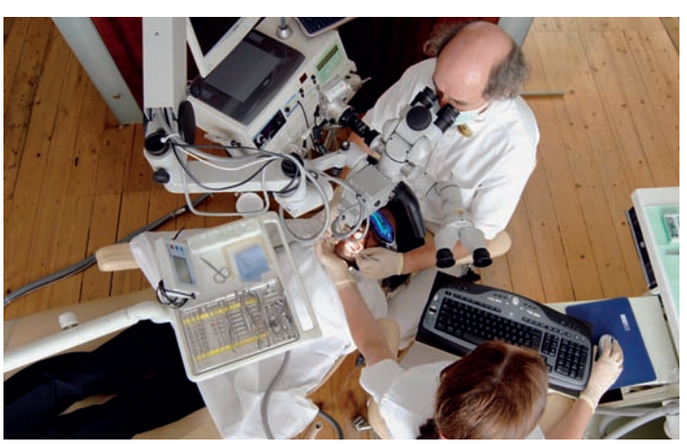
The Endo-Cart includes the pressure-regulated Stropko-air and Stropko-air/water syringes, high-speed handpieces, micromotor handpieces, an ultrasonic unit, and the tools for the warm gutta-percha filling technique. It also holds the keyboard, the graphic tablet, and the visual display unit for the clinician. The various handpieces and the ultrasonic device can be activated via one foot pedal.



39.39 Endodontic operatory II

Intraoperational view of the dental assistant, clinician, and patient. The assistant can simultaneously enter relevant clinical data.

Right: Ergonomic assistance procedures insure that the clinician does not need to look away from the dental microscope.

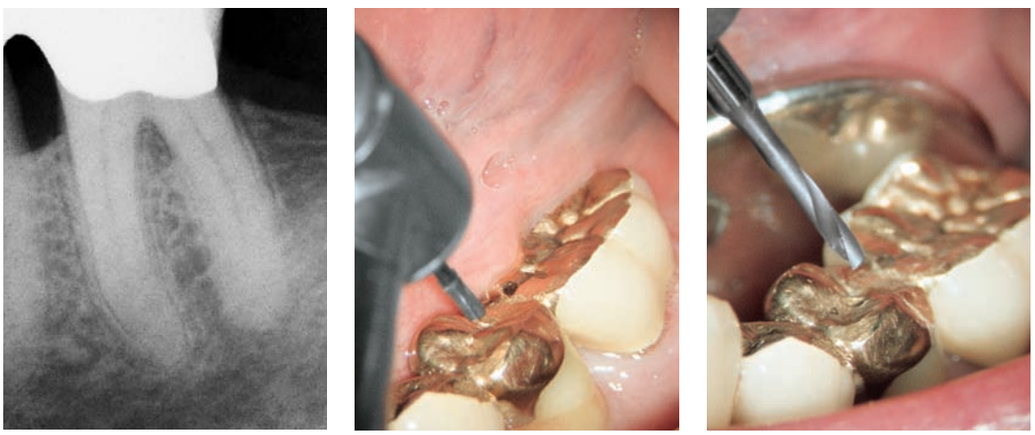


Access to the Root Canal System

Retention or Removal of the Restoration

Existing restorations must often be removed to provide adequate access to the root canal system. This provides the clinician with a clear picture of the actual long axis of the tooth, the amount of remaining tooth structure, possible existence of secondary caries, dentin infractions, vertical fractures, or canals not previously detected (missed canals). In some cases, existing restorations can be safely removed without being destroyed using systems such as Metalift (Baton Rouge, LA, USA) or CORONAflex (Kavo, Biberach, Germany), for example, and later these can be used as temporary restorations or even as the definitive restorative treatment.

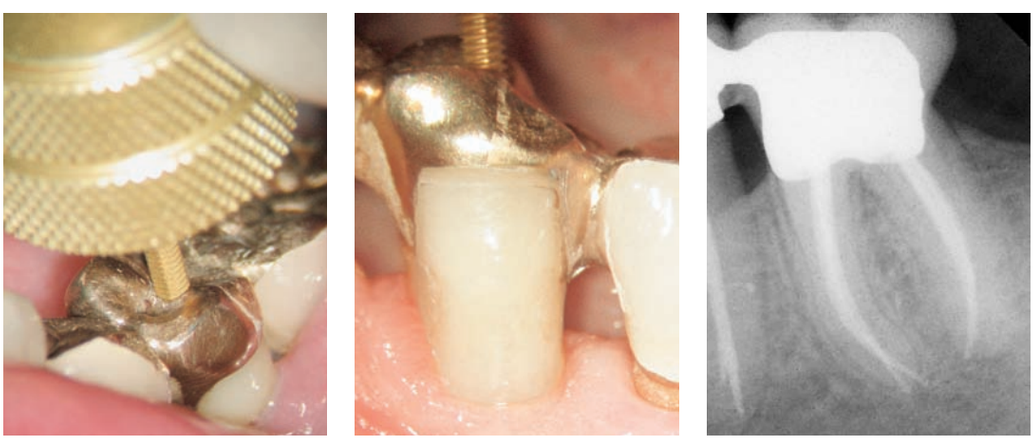
As long as the existing restoration is adequate with regard to precision of marginal fit, esthetics, function, and periodontal hygiene, retreatment can often be carried out without removing the restoration. However, this decision is often at the cost of optimum design of the access cavity and can in some cases lead to blockage of the canals by metal chips or debris. In this case, if possible the existing restoration should be removed before the retreatment of the endodontic procedure is initiated.



39.40 Removal of the restoration

Left: Preoperative radiograph of tooth 36. There was a cantilever bridge on teeth 36 and 35 with a pontic on 34. The crown on tooth 36 had become loose; every effort was made to remove the bridge as intact as possible.

Middle and right: The crown of tooth 35 was opened using calibrated predrilling with drills from the metal post system.

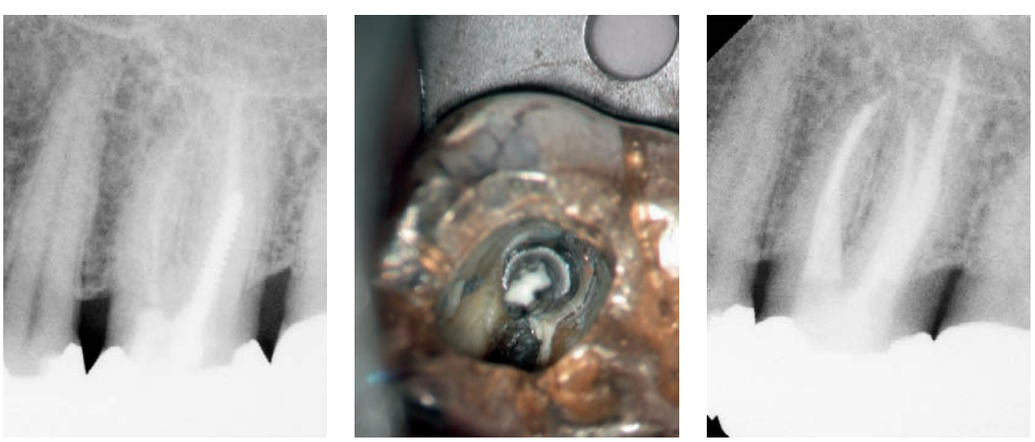


39.41 Removal of the restoration

Left: A thread cutter is screwed into the bore hole on the occlusal surface.

Middle: By activating the thread cutter, the crown is removed from the prepared tooth.

Right: Radiographic follow-up after conclusion of the treatment procedure. Tooth 35 had to be treated endodontically because of irreversible pulpitis, and tooth 36 underwent endodontic treatment because of caries with pulp exposure.



39.42 Maintenance of the restoration

Left: The preoperative radiograph revealed an incomplete root canal filling in tooth 26. Retreatment was planned with maintenance of the partial crown because it exhibited good marginal fit and there were no functional disturbances.

Middle: Access to the post through the partial crown.

Right: Radiographic follow-up 1 year later.

Removal of Posts

A common problem during endodontic retreatment is that existing posts may block access to the root canal system.

Successful post removal depends on numerous factors such as: the expertise of the clinician; the use of modern technology; individual root canal anatomy; the type, shape, and surface characteristics of the post; the type of cement used; the interocclusal access; and the position of the post within the canal (Ruddle, 1997).

In principle, posts should only be considered for removal if it can be guaranteed that sufficient sound tooth structure will remain. Alternatively, in severe cases, surgical retreatment should be offered.

Optimal access is a prerequisite for successful post removal. To this end, all of the build-up material must first be removed in order to reveal the coronal portion of the post. Stainless-steel round burs (012, 014, 016, 018) with surgical lengths, in combination with long, flame-shaped diamond burs, are indicated.

39.43 Post removal

Left: Initial orthoradial radiographic projection revealing a fractured file fragment in the mesiobuccal canal as well as posts.

Middle: A mesio-eccentric radiographic projection hints at an undetected mesiopalatal canal system.

Right: Rotated tooth 26.

39.44 Post removal

Left: Preparation of the access cavity. The build-up material was removed without destroying the heads of the posts.

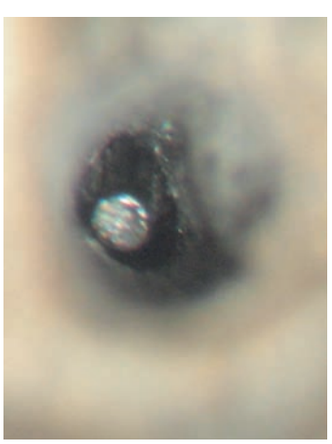
Right: Using a RotoPro bur (Ellman, Oceanside, NY, USA) in a high-speed handpiece, it was possible to loosen the screw-type posts.

39.45 Post removal

Left: Exposure of the fractured file fragment in the mesiobuccal canal using an ultrasonic tip.

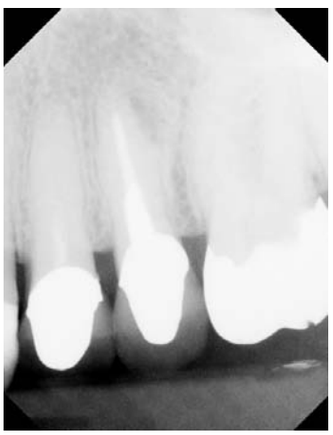
Middle: Search for the orifice of the previously undetected mesiopalatal canal, using a size 8 Kerr file.

Right: Radiograph following completion of the retreatment procedure.



In teeth with cast "post-and-core" build-up restorations, it is wise to use cylindrical carbon-steel burs (Transmetal bur, Dentsply Maillefer). In cases with multiple posts or interlocks, the build-up is initially severed in order to subsequently free up the posts. Thereafter one may use piezoelectric ultrasonic tips (e.g., ProUltra 1–5, Dentsply Maillefer). These provide a very precise and hard substance-preserving approach even in hard-to-access areas. The ultrasonic tips are moved up and down as well as circumferentially in the area of the cement interface, with minimum pressure on the post itself; the goal is to reduce retention (i.e., to break the cement bond).

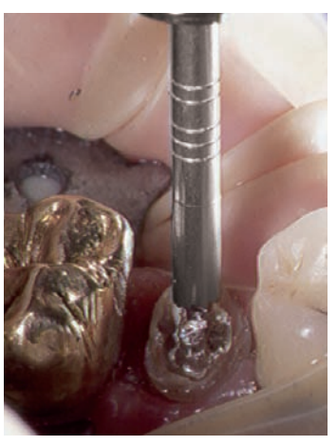
The ultrasonic treatment should be carried out in a dry field to provide optimum visual control and to prevent the clogging of debris within the canal. During the procedure, the dental assistant should use the Stropko irrigator to provide adequate cooling and also to provide a debris-free working field. If this procedure utilizing higher ultrasonic energy is expected to take time, the field must be cooled periodically with water to avoid thermal damage to the periodontium (Schwartz and Robbins, 2004). Clinical experience has shown that about 10 minutes of vibration with ultrasonic energy will successfully remove metal root posts.



39.46 Removal of a cast post and core

Left: Initial radiograph of tooth 25 (orthoradial projection).

Right: The eccentric projection provides important information about the dimension of the root post, its oval shape and substantial thickness, which could not be detected or appreciated on the standard orthoradial film.

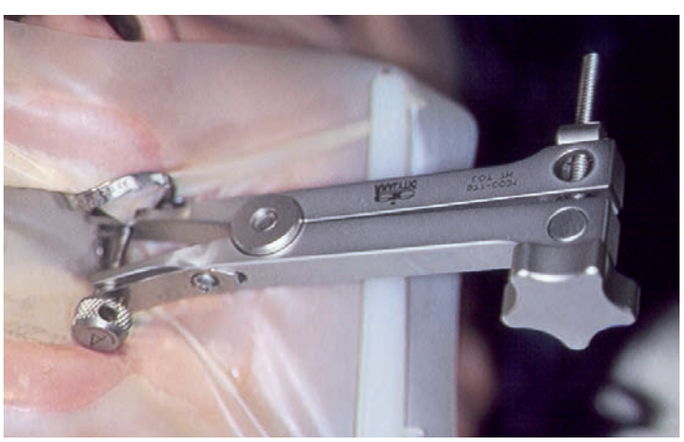


39.47 Removal a cast post and core

Left: Clinical view following removal of the crown showing the cast post and core.

Middle: Depending upon the number of posts, it is often necessary to section the core.

Right: Following initial use of the Ruddle Post Removal System (SybronEndo, Orange, CA, USA), the post is measured coronally to receive a thread cutter.



39.48 Removal of a cast post and core

The extraction forceps of the Ruddle Post Removal System with its thread cutter was affixed and supported by the tooth, so that the post could be removed in the precise axial direction from the root canal by turning the knob.

Left: Radiograph following retreatment and adhesive build-up of tooth 25.

An alternative technique for loosening posts uses so-called Roto Pro burs (Ellman International, Hewlett, NY, USA). These noncutting, tapered, abrasive burs are used with a high-speed handpiece in a counterclockwise motion circumferentially in contact with the post. The resultant vibrations often lead to loosening of the post.

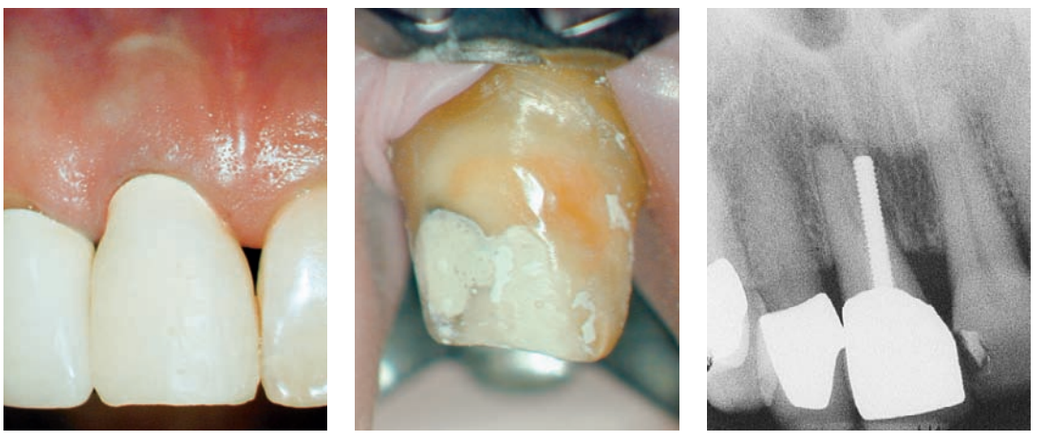
Alternatively, special systems developed specifically for post removal can be used (Gonon, Ruddle). Posts with a diameter greater than 0.60 mm can be removed using the Ruddle Post Removal System (SybronEndo). In the case of posts fractured deeply within the root canal, the Masseram System (Micro-Mega, Besançon, France) should be used because it is less damaging to the remaining tooth structure.

39.49 Post removal

Left: Initial clinical situation with a temporary crown on tooth 11.

Middle: After removal of the crown, a large post is seen in tooth 11.

Right: Initial radiographic situation. The post has perforated the root in the coronal third, labially.

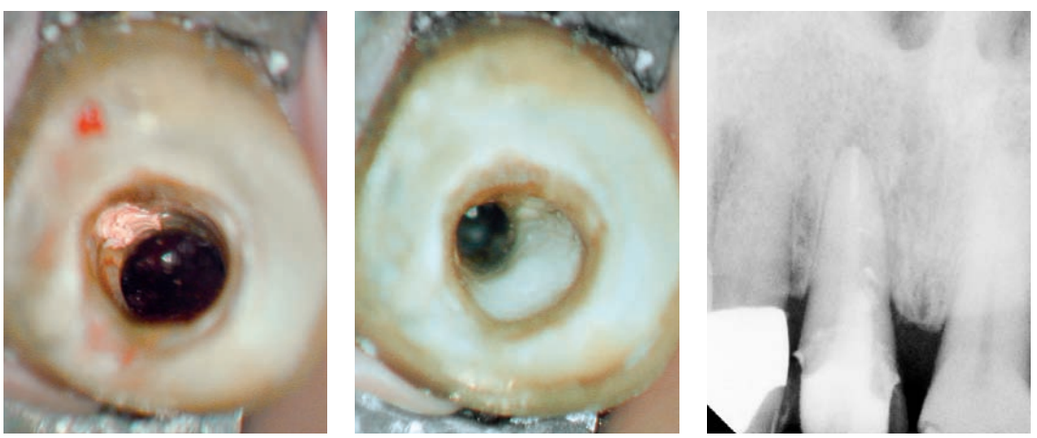


39.50 Post removal

Left: Clinical appearance of the large perforation defect following removal of the post.

Middle: Closure of the defect using calcium sulfate (Capset).

Right: Radiograph following retreatment of the root canal.

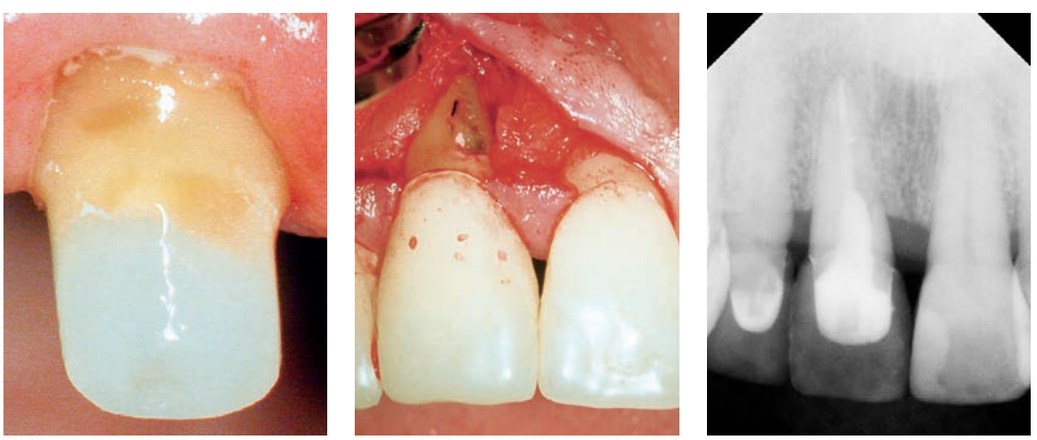


39.51 Post removal

Left: Adhesive build-up using a glass-fiber post and composite resin.

Middle: Labial view of the perforation defect, which was followed by periodontal treatment with guided tissue regeneration.

Right: Radiograph taken 2 years later shows a stable clinical situation without increased probing depths, as well as an intact periodontal ligament space.



Owing to the rise in demand for esthetic restorations, tooth-colored root canal posts made of zirconium silicate or fiber-reinforced composite resins are increasingly being used. However, because of the nature of these materials, as well as the requirement for adhesive cementation, certain challenges are presented by cases requiring retreatment.

Neither ultrasonics nor tools such as the Gonon or the Ruddle post-removal systems possess the ability to remove zirconium posts. The problems reside in their hardness — similar to that of diamond — and their brittleness; both characteristics make their removal from a root canal extremely difficult. Attempts can be made at removal using the trepan bur of the Masseran set.

Using the various commercially available kits (e.g., DT Post Removal Kit, VDW, Munich, Germany), it is possible to successfully remove fiber posts. The instrument is inserted in the axial direction centrally in the post, and the heat development at the tip softens the composite resin matrix while effectively cutting the fibers. Any residual fibers and cement within the canal can be subsequently removed using ultrasonics.

39.52 Initial situation

Left: Clinical view of tooth 12 with a fractured zirconium ceramic build-up at the gingival margin.

Right: The initial radiograph showing a fractured zirconium post, which was extending into the apical third of the root. Apical to the post is a fractured Lentulo spiral fragment.

39.53 Removal of the post and the fractured Lentulo spiral

Left: Occlusal view of the zirconium post.

Middle: Root canal following post removal using a Masseran trepan bur. On the floor of the root canal are remains of the adhesive composite.

Right: Occlusal view of the Lentulo spiral following removal of the composite resin using a diamond-tipped ultrasonic instrument.

39.54 Postendodontic treatment

Left: Build-up of the tooth using a cast post and core.

Right: Three-year follow-up radiograph. Before definitive restorative therapy, the tooth was orthodontically extruded to provide space for a sufficient ferrule restoration.

Access to the Apex

Removal of Gutta-percha

Gutta-percha should be removed using the crown-down technique first in the coronal, then in the middle, and finally in the apical third of the root. This procedure minimizes the danger of forcing old root-canal filling material, infected debris, or the irrigating solution into the periapical tissues.

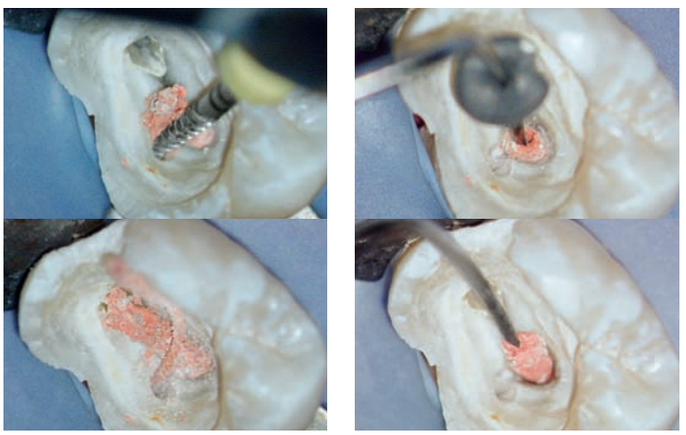
If the root canals still exhibit a certain taper, rotary NiTi files of taper .04 or .06 can be used. At speeds of 1200–1500 rpm, the gutta-percha is warmed by the friction and transported out of the canal coronally owing to the cutting design of the files (Bramante, 2000). An alternative is to soften the gutta-percha using a heat carrier and then to remove it with a Hedström (H) file.

In very narrow or curved canals, the use of chemical solvents (chloroform, eucalyptol, halothane) has proved effective for the removal of gutta-percha, in combination with small K or H files. In limited doses and with well-controlled application, the use of chloroform was not associated with any harmful effects (McDonald and Vire, 1992).

39.55 Removal of gutta-percha I

Left: Removal of gutta-percha using a .06 Profile (size 30), at 1200–1500 rpm (Dentsply Maillefer).

Right: Removal of gutta-percha using the heated tip of the Touch 'N' Heat instrument.

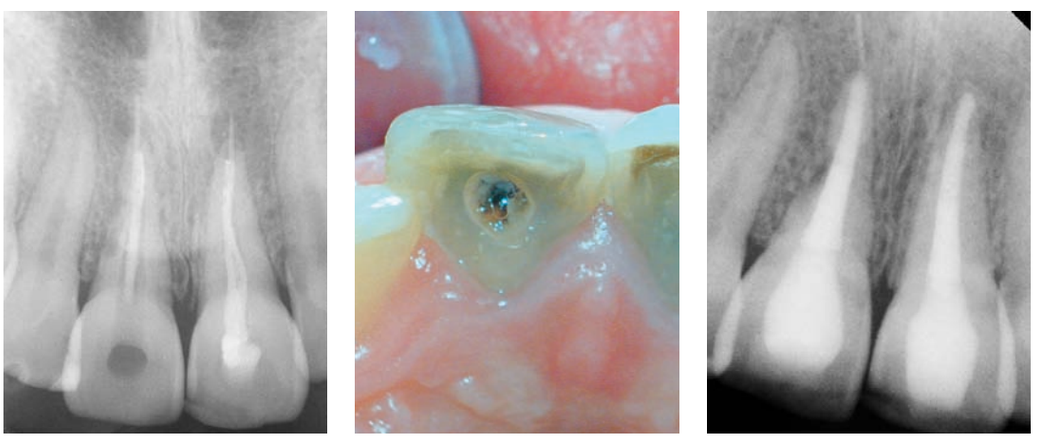


39.56 Clinical example of gutta-percha removal

Left: Teeth 11 and 21 with associated AP; tooth 11 shows obvious root resorption following anterior tooth trauma. Both teeth had overextended gutta-percha fillings and less than complete, 3D filling of the canal system.

Middle: Tooth 11 was left open because of persisting discomfort over several months.

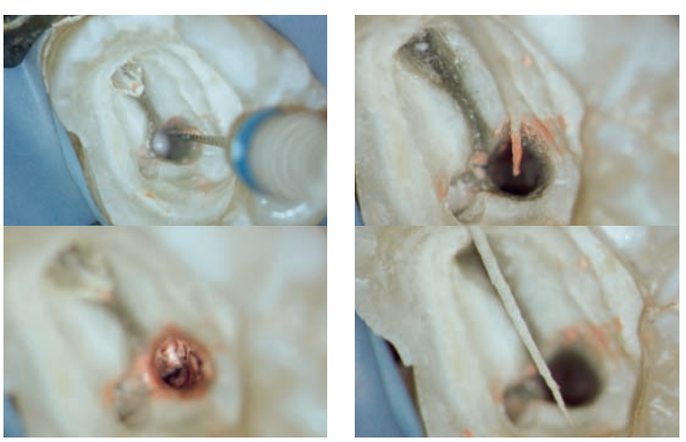
Right: The gutta-percha fillings were removed with H files. Note the persisting overextended gutta-perch in tooth 11.



39.57 Removal of gutta-percha II

Left: Chemical dissolution of gutta-percha using chloroform in combination with a size 15 Kerr file (above). View of the dissolved gutta-percha (below).

Right: Removal of the dissolved chloropercha mass using paper points until they no longer exhibit any gutta-percha residue.



Removal of Root Canal Pastes and Cements

Paste fillings must be removed with great care to prevent apical extrusion and blockage, the possible consequences of which are postoperative pain or paresthesia due to the potential neurotoxicity of the paste (Serper et al., 1998).

Basically, one can differentiate two types of paste: soft and hard. Eugenol-containing pastes (e.g., N2) can be removed without difficulty using solvents such as Endosolve "E" (Septodont, Paris). Endosolve "R" can be helpful for the removal of hard pastes with an acrylic resin base (e.g., AH 26).

A special challenge is presented by the so-called "Russian pastes," which consist of a resorcinol-formaldehyde-acrylic base, because they exhibit a stone-hard consistency and there is no known effective dissolving solution (Vranas et al., 2003). Piezoelectric ultrasonic energy with microscopic control enables removal of these pastes in the straight coronal portion of the root canal.

Paste-type root canal fillings often exhibit porosities in the apical regions of the root canal, therefore reinstrumentation to the apex using hand instruments may be possible.

39.58 "Russian paste"

Radiograph of a resorcinol-based root canal filling.

Left: Following preparation of the access cavity, the hard, reddish root canal filling is visible.

39.59 Removal of the "Russian paste"

Left: Removal of the cement filling in the straight portion of the canal using ultrasound and a clinical microscope.

Right: Probing for porosities in the root canal filling using hand instruments (Kerr files, sizes 8, 10, and 15).

39.60 Treatment result

Radiograph following retreatment.

Left: Two-year follow-up with definitive restorations.

Removal of Silver Points

Silver point fillings were introduced more than 70 years ago to facilitate the filling of especially narrow and curved root canals. The biggest problem with this technique is the corrosive behavior of silver on contact with tissue fluids, which ultimately leads to leakage.

The resultant corrosion products include silver sulfide, silver sulfate, silver carbonate, and silver amine hydrate. These substances can be highly cytotoxic and in the context of endodontic retreatment can elicit acute postoperative inflammatory reactions (Goldberg, 1984).

The typical preparation for silver point placement demonstrates an almost parallel and round canal shape in the apical 2–3 mm. Coronally, however, one often observes cracks or grooves. After removing all the build-up material without damaging the silver point, the point should be engaged as much as possible with fine, flexible K files (sizes 8, 10, and 15) in combination with chloroform or Endosolve E.

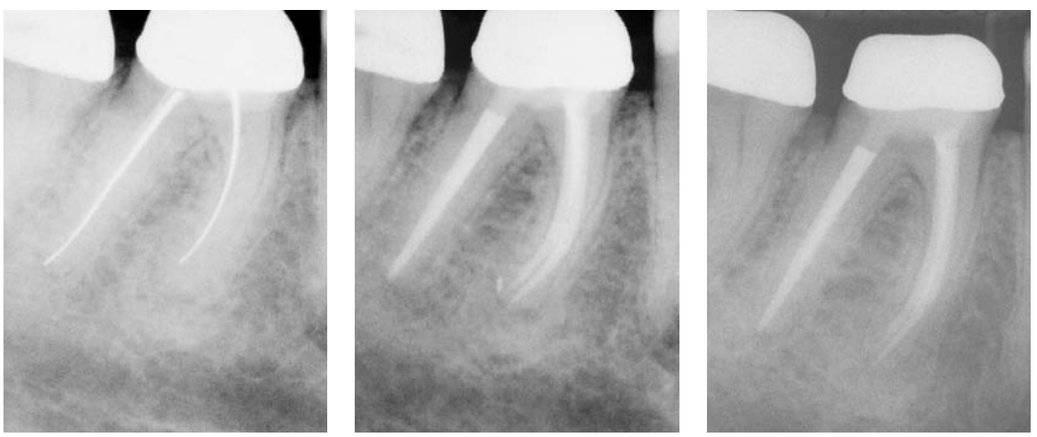
Only then can an attempt be made to remove the silver point itself using ultrasonic devices, H files, or special instruments (e.g., Mini Steglitz or microcannulas).

39.61 Removal of silver points

Left: Silver point filling in tooth 46. The treatment plan involved new prosthetic treatment.

Middle: Radiographic view following removal of the silver point and the root canal filling.

Right: The six-month posttreatment radiograph is unremarkable.

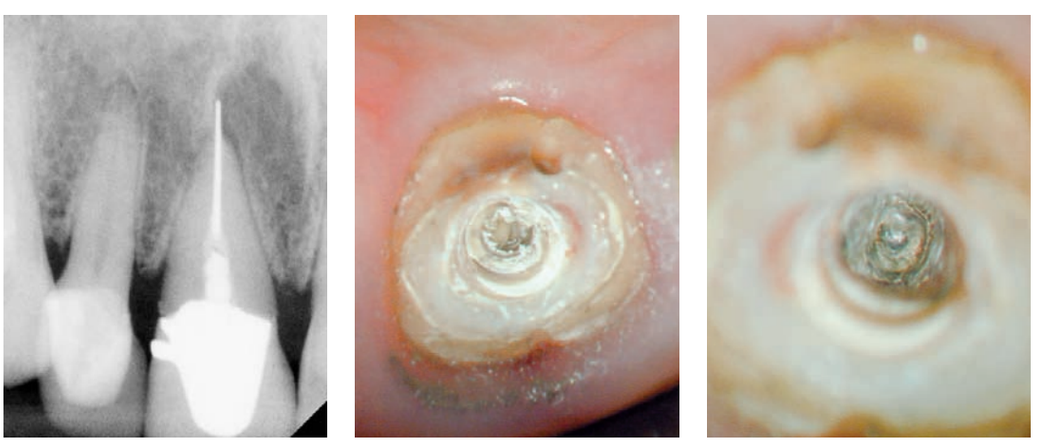


39.62 Access to the apex

Left: Tooth 11 has acute apical periodontitis, a silver point as the root canal filling, and a post-and-core build-up.

Middle: Clinical view following removal of the crown and the post. A fractured Lentulo spiral fragment at the level of the post was also detected.

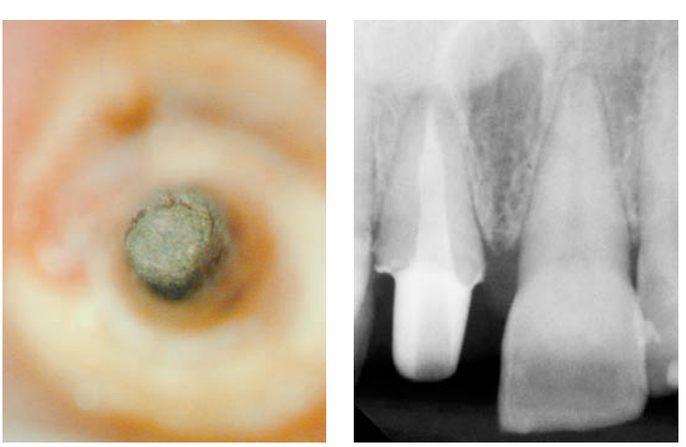
Right: Fracture of the silver point toward the apical end, resulting from the attempt to remove it using ultrasonics.



39.63 Silver point removal and endodontic retreatment

Left: Root canal filled with MTA in its apical third because of a severely transported physiologic foramen.

Right: Radiograph taken following root canal filling and the placement of an adhesive build-up with a glass-fiber post and composite.

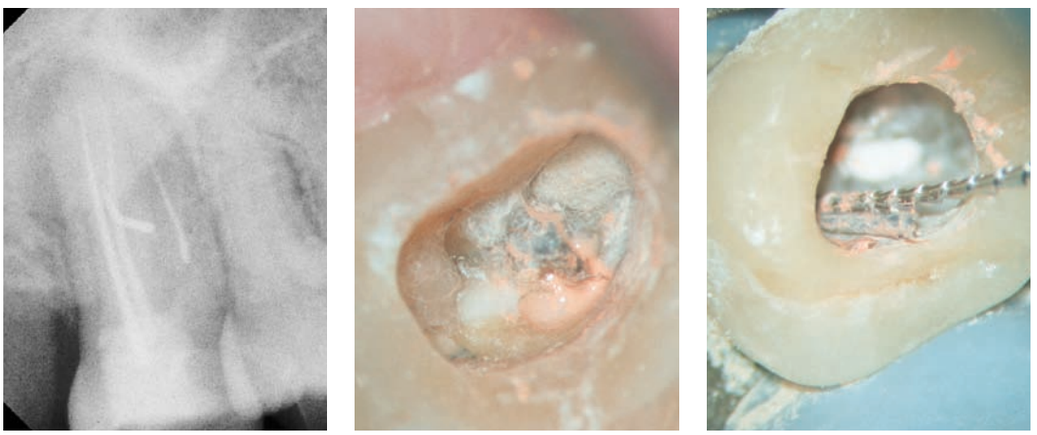


Removal of Carrier-based Gutta-percha Fillings

Carrier-based gutta-percha fillings such as the Thermafil system (Dentsply, Maillefer, Ballaigues, Switzerland) consist of a flexible post coated with α-phase gutta-percha. The initially incorporated metal carrier was replaced by a resin carrier. The plastic post has a groove in the axial direction.

Acrylic resin carriers are removed using rotary NiTi files of taper .04 at a rotation speed of about 1200 rpm with light pressure applied in the apical direction in the region of the axial groove. The friction warms the gutta-percha, which can then be moved in the coronal direction. As soon as resistance is encountered, the NiTi file is changed to one of .06 taper, which is used at a speed of 300 rpm. Because of the stronger contact of the file between the canal walls and the carrier, the post can usually be removed in this manner.

An alternative is the use of H files following the removal of gutta-percha around the carrier with small K files and solvent material. Any gutta-percha remaining within the root canal system is subsequently removed by careful irrigation with chloroform and drying with paper points.

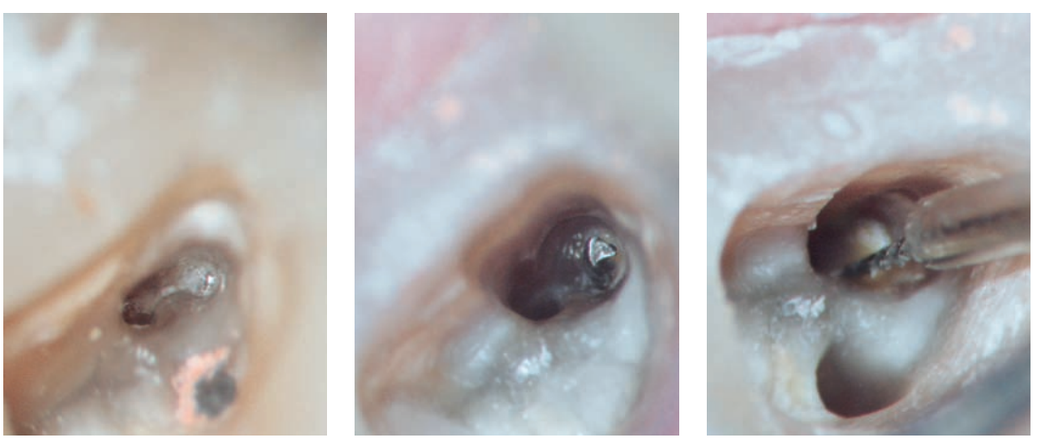


39.64 Removal of Thermafil Carriers

Left: Tooth 17 with an associated periapical radiolucency. The palatal sinus tract was revealed using a gutta-percha point.

Middle: Dissolving the gutta-percha around the Thermafil carrier using chloroform.

Right: Removal of the carrier with a size 40 H file.



39.65 Continuance of the above retreatment

Left: Fractured NiTi file within the mesiobuccal canal.

Middle: Exposure of the coronal 3 mm of the instrument fragment.

Right: A metal microcannula (Cancellier Tube) was filled with composite (Core Paste) and inserted over the exposed instrument fragment.

39.66 Continuance of the above retreatment

Left: The NiTi fragment cemented into the microcannula.

Right: The 1-year follow-up radiograph shows complete healing of the lesion.

Removal of Separated Instruments

The possibility of removing a separated instrument fragment is determined primarily by the morphology of the root, the thickness of the surrounding dentin, as well as the presence of concavities in the root surface. If it is possible to expose the instrument fragment by about a third of its length, it is usually possible to remove it from the canal.

If it proves impossible to achieve direct access to the separated instrument (e.g., if fracture occurred apical to the canal curvature), in general there is little possibility for successfully removing the fractured fragment. In such cases, one may attempt to use small, flexible files to bypass the instrument fragment and subsequently obturate the root canal system. If neither of these procedures is successful, and clinical or radiographic symptoms persist, one must consider a microsurgical procedure or even extraction of the affected tooth.

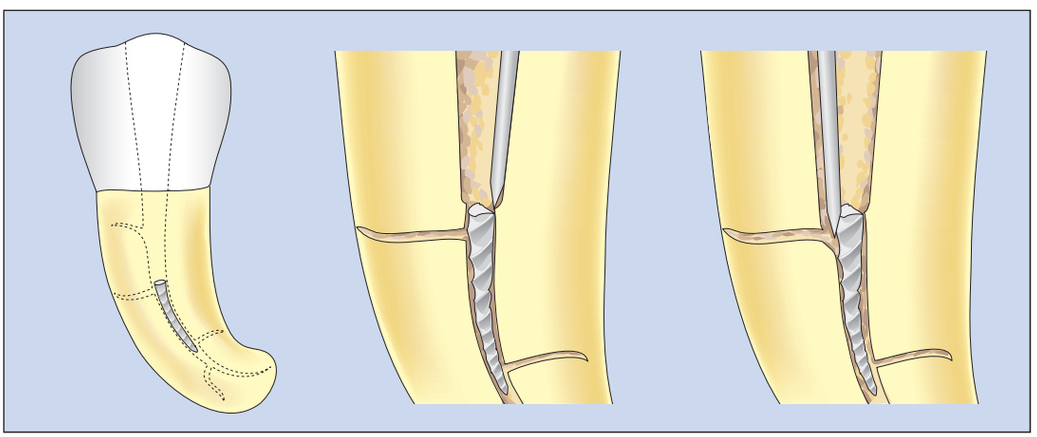
The material of the separated instrument (stainless steel or NiTi) also has an important influence on its removal. NiTi files generally break because of their brittleness when ultrasonic energy is used to attempt removal, and this renders the treatment considerably more difficult.

39.67 Cavity design

Left: Creation of straight-line access from the access cavity to the coronal end of the fractured instrument fragment.

Middle: Using a modified Gates-Glidden bur, a staging platform is created at the coronal end of the separated instrument. This permits use of ultrasonic tips lateral to the instrument fragment.

Right: Targeted and precise exposure of the fractured instrument fragment using ultrasonic tips (e.g., ProUltra #3, Dentsply Maillefer).

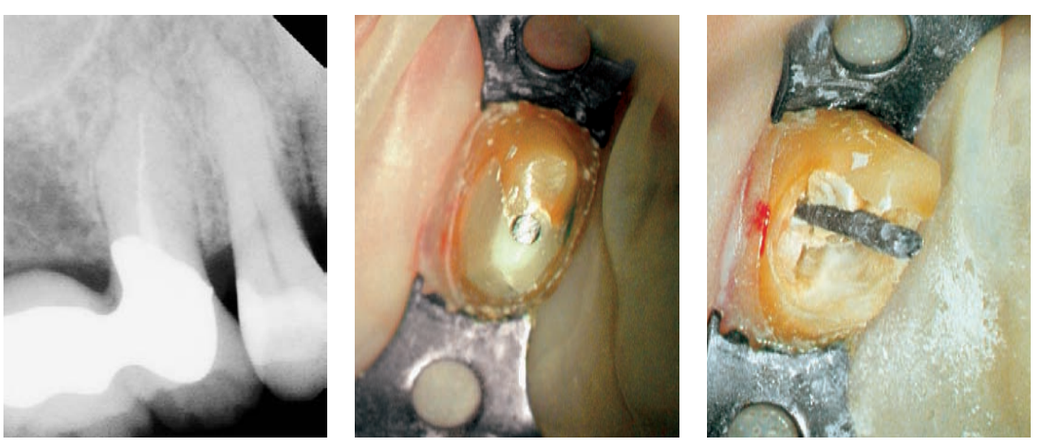


39.68 Clinical case I

Left: Tooth 15 with CAP; a new prosthetic restoration is planned. The radiograph reveals a post as well as two separated instruments.

Middle: Clinical view following removal of the old crown.

Right: Removal of the build-up material and loosening of the post using the Roto-Pro bur.

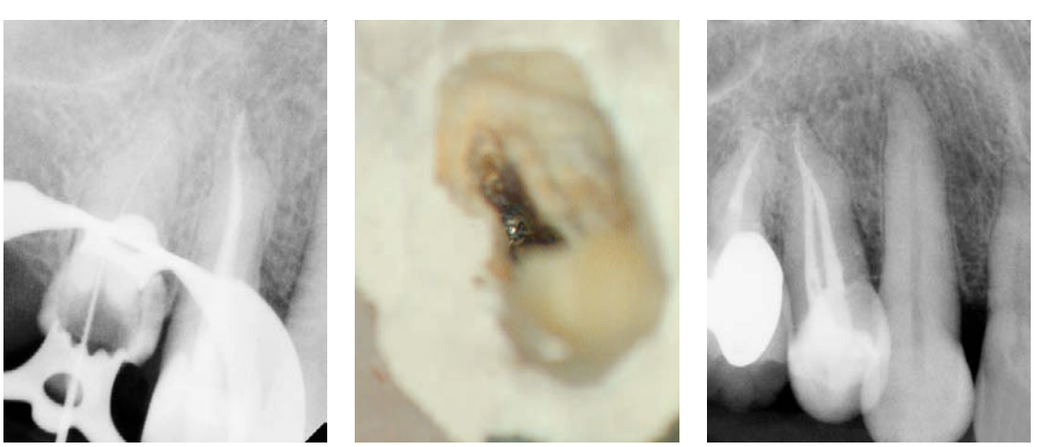


39.69 Removal of separated instruments

Left: Working radiograph with a size 10 file extending to the radiographic apex.

Middle: View of the apical third of the root showing the instrument fragment.

Right: Follow-up radiograph after endodontic retreatment.

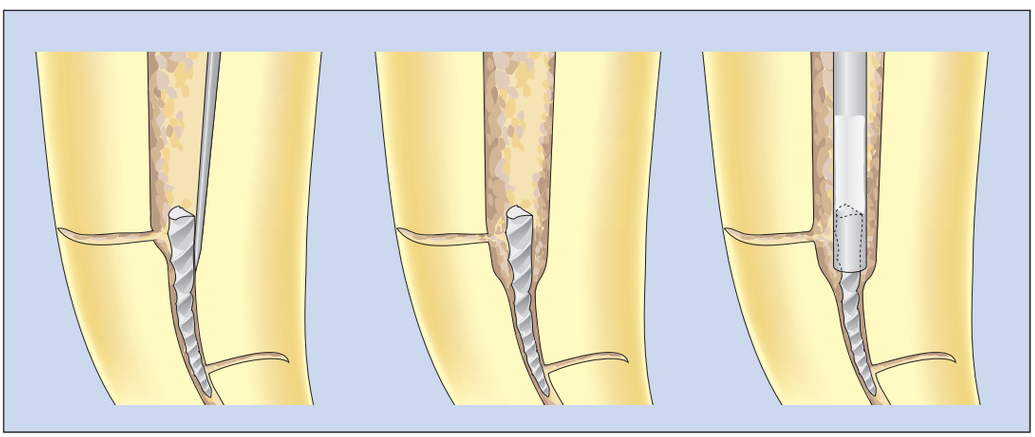


The first clinical step is to use hand instruments in ascending sizes to create space for the Gates-Glidden burs (sizes 1–4), which relocate the canal orifices away from the furcation areas and provide a straight, slightly tapered pathway for subsequent instruments.

Using modified Gates-Glidden burs, which are shortened to the height of the largest horizontal circumference, it is possible to create a "staging platform" around the separated instrument fragment. This permits the use of ultrasonic tips lateral to the separated instrument for removal of dentin in the coronal 3 mm.

The tip is then positioned on the dentin platform between the separated instrument fragment and the canal wall and, without water spray, rotated in a counterclockwise manner — by which the broken instrument will often be released.

If this procedure is not successful, one may use microcannulas to attempt the removal. For this procedure a cannula is selected that can be passively inserted into the root canal above the exposed separated instrument. The instrument fragment can then be mechanically wedged in the cannula or glued to it.

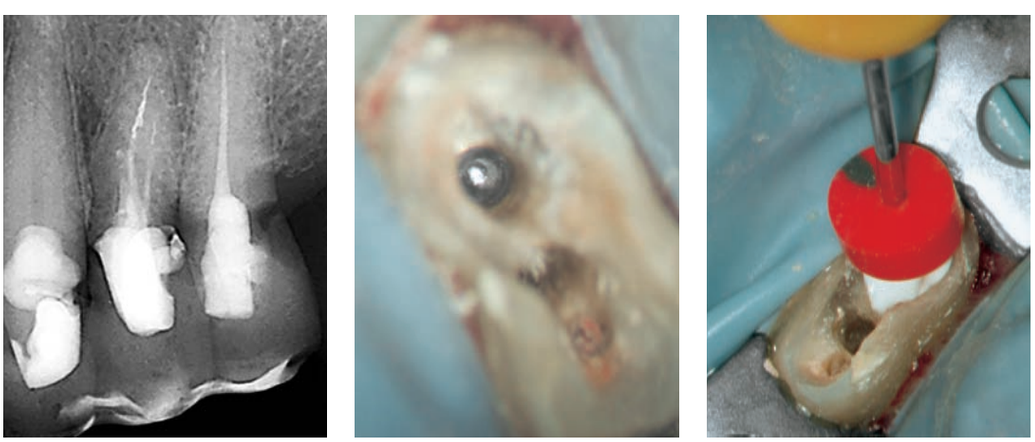


39.70 Creating a staging platform

Left: The long, thin titanium ultrasonic tips (ProUltra #6, Dentsply Maillefer) permit working within the root canal while preserving as much tooth substance as possible.

Middle: The goal is to free up the coronal third of the instrument using the ultrasonic tips.

Right: A microcannula (Cancellier Tube) of a size corresponding to the instrument is selected and filled with an autopolymerizing resin, then inserted over the instrument fragment in order to withdraw it once the resin has hardened.

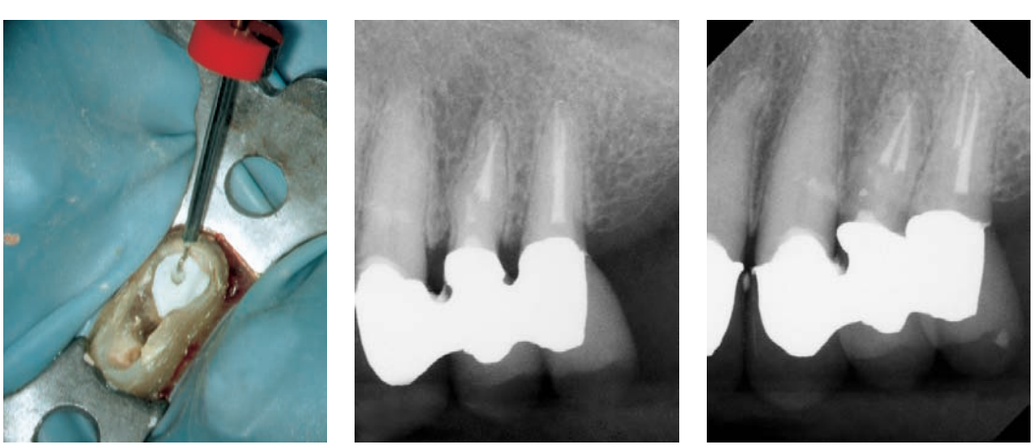


39.71 Clinical case II

Left: Several separated instrument fragments within the root canal system of tooth 14.

Middle: Preparation of straight-line access to the separated instruments.

Right: Grasping the instrument fragment following exposure of the coronal 3 mm by means of a microcannula and autopolymerizing resin.



39.72 Successful removal and root canal filling

Left: Removal of the separated file fragment using a microcannula.

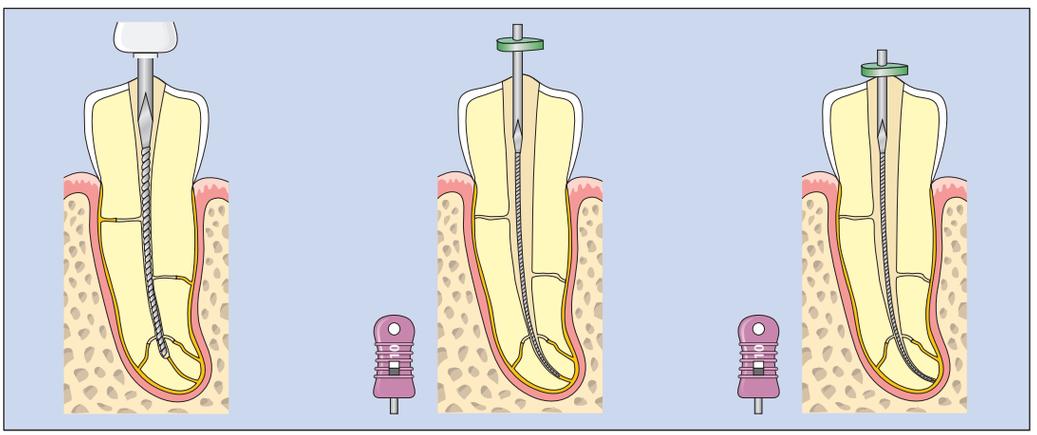
Middle and right: Radiographic condition following retreatment of the root canals of teeth 14 and 15, obturation, and post space preparation.

Management of Transported Foramina

In the course of endodontic retreatment, the clinician is often confronted with problems such as canal blockage, step formation, perforation, or overinstrumentation of the apical foramen. A transported root canal frequently contains residual pulp soft tissue as well as compacted dentin debris within the final portion of the canal system. These areas are often also infected and cause lesions of endodontic origin.

For this reason, clinicians should attempt to eliminate blockage or to bypass ledges in order to instrument the entire root canal system in three dimensions, and to subsequently clean, shape, and fill it successfully. A determining factor in this regard is, again, an ideal coronal and root canal access preparation to increase tactile sensation and the ability to insert prebent instruments without hindrance to the level of the blockage or ledge.

Using a size 10 K file, which is prebent at around 45° in its apical 0.5–1 mm, one now attempts to probe the blocked canal segment and with slight apical force find and follow the original anatomic course of the canal. This procedure should be accompanied by copious irrigation with sodium hypochlorite and EDTA.

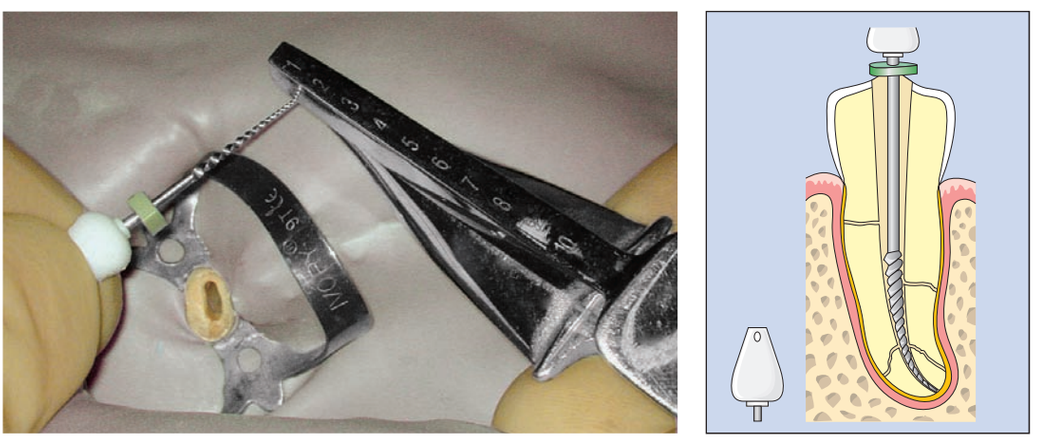


39.73 Transported foramen

Left: The instrument has actually created a ledge outside the original canal course. Note the inadequate tapered preparation of the coronal third of the canal.

Middle: Following adequate coronal enlargement, a prebent instrument can negotiate the original course of the canal.

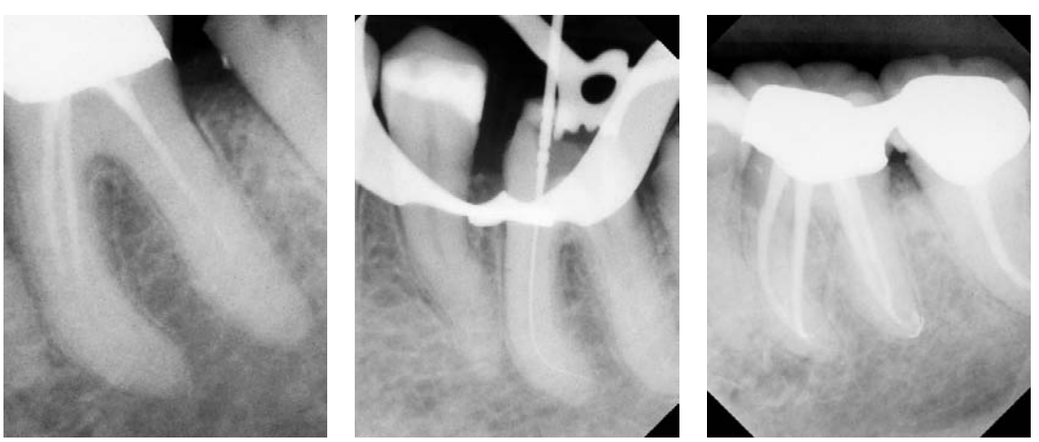
Right: Using a size 10 Kerr file, it is possible to go beyond the ledge and achieve root canal patency.



39.74 Getting beyond a ledge: instruments and theory

Special instrument for prebending a file (Buchanan File Bender, SybronEndo, Orange, CA, USA).

Right: The prebent GT hand file with a .06 taper was used to smoothen the ledge with the balanced force technique to the complete working length.



39.75 Clinical case, overcoming a step/ledge

Left: Tooth 36 with an underfilled root canal system. The mesial canals were blocked and showed clear step formation.

Middle: Traversing the ledge; radiograph shows working length determination with a .04 taper NiTi file.

Right: Follow-up radiograph after root canal filling.

Additional Topics

G

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40 Endodontic Surgery

The term "endodontic surgery" encompasses a variety of invasive procedures that have both surgical and endodontic aspects in equal measure. The most common endodontic surgical procedure is the root resection (apicectomy). A standard clinical procedure, apicectomy is characterized by removal of the root tip, retrograde preparation of accessible root canal areas, and hermetic retrograde canal closure, with the removal of inflamed extraradicular tissue and — if present — any extruded root canal filling materials.

Other endodontic surgical procedures are hemisection and root amputation, intentional reimplantation, and transdental fixation. The latter two examples generally play a minor role (intentional reimplantation) or no role at all (transdental fixation), while hemisection/root amputation could be considered for periodontal and/or restorative reasons (e.g., grade 2 or 3 furcation involvement). This chapter will focus on root resection because of its significance within the spectrum of endodontic surgical procedures.

The development of the surgical procedure of root resection can be traced back to Partsch (1899). Although these surgical techniques have been continually refined over the past 100 years, it is the newest technical developments and better biologic and microbiologic understandings that have given the procedure new impetus over the past 10 years — whether initiated by endodontologists or modified from other dental specialties. Of particular importance from a technical point of view are the following:

- introduction of the operating microscope;
- introduction of microsurgical instruments and ultrasonically energized preparation devices;
- use of biocompatible materials for the retrograde closure of the root canal;
- refined surgical techniques.

Surgical removal of the root apex was originally justified by the complexity of the root canal system in its apical area. Root canal ramifications and lateral canals inaccessible with conventional root canal treatment allow microorganisms to survive, thus maintaining apical periodontitis.

Long-term clinical studies, however, have demonstrated that adequately performed conventional endodontic therapy, even with a certain degree of infection in the root-canal space, still results in success rates of between 75% and 85% (Weiger, 1998, 2005), suggesting that failures are an exception. Persistence of periapical lesions can be due to intracanalicular etiology as well as the result of extraradicular infections or so-called true cysts, or — in rare cases — foreign-body reactions.

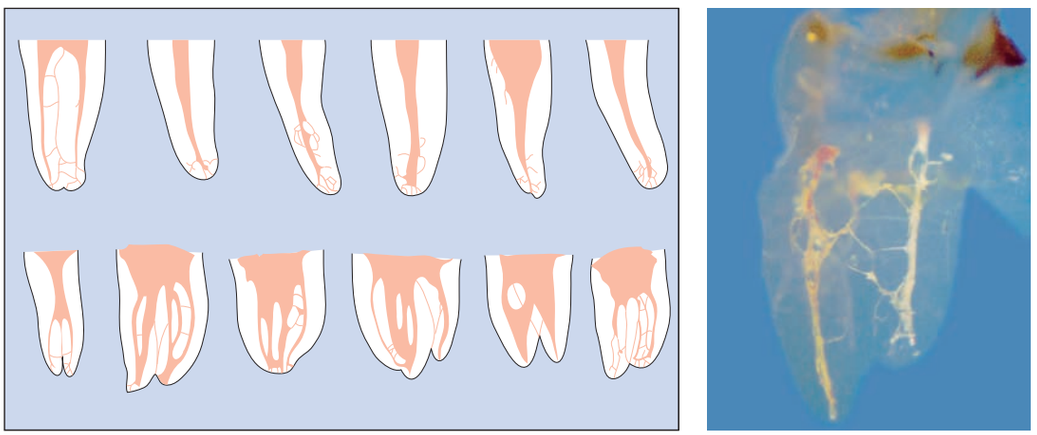
For persisting lesions that cannot be successfully managed by orthograde re-treatment, apicectomy offers the possibility of eliminating microorganisms remaining in the apical portion of the canal space, as well as preventing them from accessing the periradicular space by means of a retrograde filling. During the surgical procedure potential microbiota from extraradicular origin are eliminated as well.

Indications for Apicectomy

The prerequisite for an apicectomy is a restorable tooth with a failed endodontic treatment but adequate remaining periodontal support that permits apical surgical access. Any coronal leakage must be prevented prior to the surgical procedure (Löst, 2001). In general, conventional retreatment is the first option if the root canal can be accessed.

Apicectomy is indicated when other types of treatment appear too complex or a successful outcome is uncertain, for example removing a large post under an intact and functional full coverage crown. The decision for apicectomy must also include considerations such as clinician's experience and availability of appropriate technical equipment.

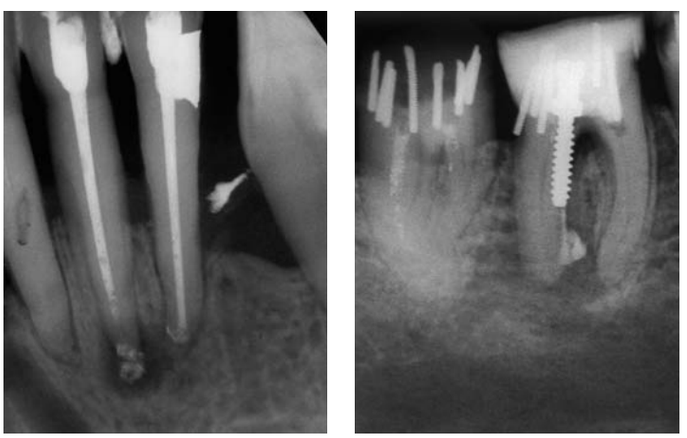
The aim of the apicectomy is cleaning and shaping of accessible root canal areas followed by sealing with a retrograde filling that prevents percolation of microorganisms apically (coronal and apical leakage).



40.1 Root canal systems

Left: Hess demonstrated the high complexity of the root canal system. Lateral canals and isthmuses are clearly visible.

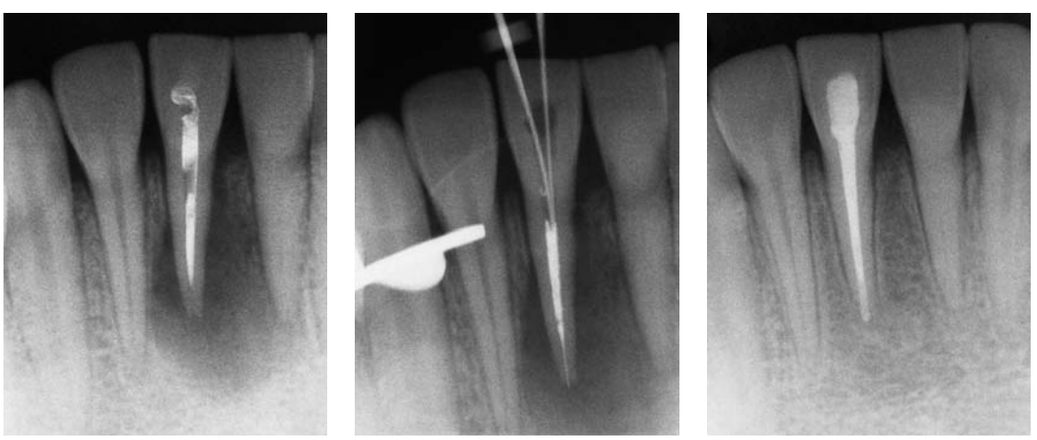
Right: The transparent view of the tooth displays the fine ramifications of the canal system. (Courtesy of Dr. Reuver.)



40.2 Contraindications for a surgical procedure

Left: Anterior tooth with an apical lesion and extensive periodontal attachment loss.

Right: Mandibular molar with multiple perforations into the furcation area resulting from a misaligned post and dentinal pins. This tooth cannot be saved.



40.3 Endodontic therapy using conventional orthograde retreatment

Left: Mandibular anterior tooth with a large apical lesion.

Middle and right: Reinstrumentation of both root canals, followed by application of calcium-hydroxide medicated dressing, resulted in healing of the apical lesion.

Apicectomy is only indicated when initial treatment, and usually retreatment, have failed and the intraradicular and/or extraradicular cause persists. In such cases, despite previous endodontic efforts, one must assume the presence of bacteria within the root canal system, which are not accessible by conventional endodontic treatment, or individual persisting infection of extraradicular origin, and/or a true radicular cyst.

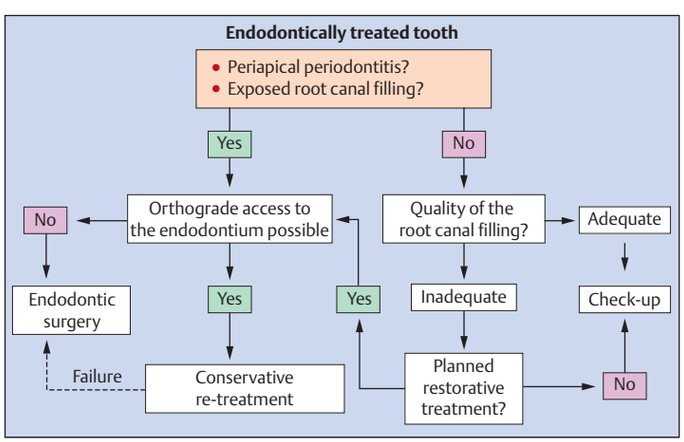
Apical periodontitis (AP), as a rule, does not represent a primary indication for apicectomy, with rare exceptions (see later). Likewise, apparent root canal obliteration, abnormal root canal conditions, separated root canal instruments, extruded root canal filling material, and perforations can be treated by orthograde conventional means. Even in cases of separated root canal instruments that could not be removed, healing of an apical lesion is generally possible (Parashos and Messer, 2006).

40.4 Clinical case I

Left and middle: Despite an apparently acceptable conventional endodontic result, a periapical lesion and fistula persisted.

Right: Following surgical intervention the lesion is in the process of healing.

(Source: Textbook of Endodontology. Oxford: Blackwell Munksgaard, 2003.)



40.5 Flow chart

"Decision making" for a tooth with previous root canal treatment requiring reconstructive procedures.

40.6 Clinical case II

Left: The maxillary molar has an apical lesion and an adequate coronal restoration.

Middle: Due to the potential risk of fracture during post removal, an apicectomy with retrograde filling was carried out.

Right: Radiograph indicates healing of the lesion.

Diagnosis

The clinical examination of the tooth consists of careful inspection of the surrounding gingival and mucosa, evaluation of the attachment level, as well as critical examination of any restorations. The adjacent teeth should be included in the clinical examination, as incision can involve adjacent teeth as well.

An important factor is the *radiographic* evaluation. Radiographs taken using paralleling and orthoradial projection are essential; or in some cases eccentric radiographs, in order to evaluate without distortion the apical anatomy in relation to surrounding anatomic structures. It is also recommended to use additional radiographic imaging techniques to visualize structures such as the mandibular canal or the mental foramen.

In complex cases, a 3D computed tomography (CT) evaluation (e.g., mandibular premolars and molars as well as maxillary molars with palatal roots involved) provides not only critical preoperative information concerning the feasibility of the procedure, but also assists in surgical planning with regard to the extent of the lesion and the exact location of the root tip in relation to the buccal/palatal bone, the mandibular canal, or the maxillary sinus.

40.7 Periodontal condition

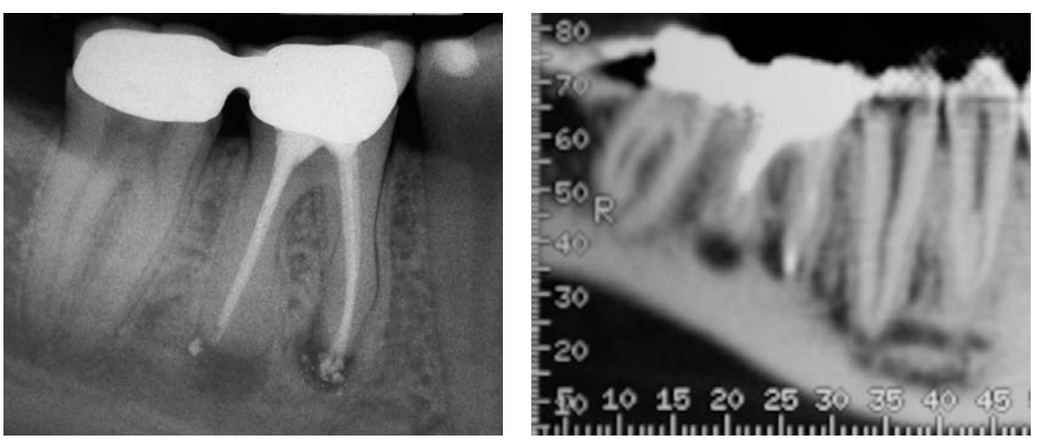
Left: Fistula in relation to tooth 22. The marginal gingiva appears healthy.

Right: Apical pathology on a mandibular anterior tooth, with acute gingivitis. The crown margins are inadequate.

40.8 Radiographic diagnosis

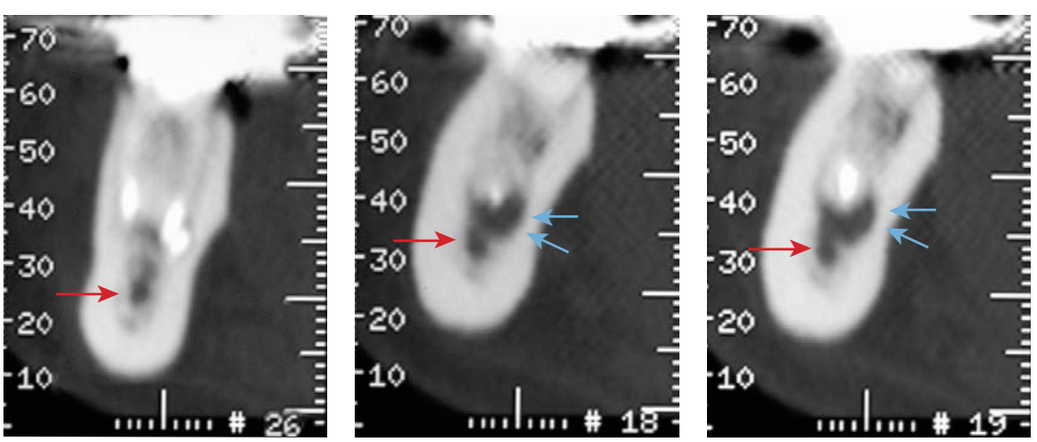
Left: Periapical radiograph of a mandibular first molar. The mandibular canal appears to be sufficiently distant from the root apex.

Right: Overview with CT. The scale identifies the location of the axial sections in Figure 40.9.



40.9 CT section diagnosis

Section 26 shows the mesial, and sections 18 and 19 the distal root. It is evident that the lesion from the distal root has already reached the mandibular canal. Red arrow: mandibular canal; blue arrow: periapical lesion.



Dental Microscope

The introduction of the dental microscope into dentistry in the early 1990s opened the door for true microsurgery. Using appropriate magnification and miniaturized instruments, it optimizes soft-tissue management, allows a smaller access to the apical area, exacting retrograde preparation, and, finally, precise placement of the retrograde filling material.

Magnification of up to ×25, in combination with optimal and shadow-free illumination of the operating field allows excellent inspection of important anatomic details. The microscope can help to localize isthmus formations, C-shaped configurations, noninstrumented root canal areas, etc. It can also assist in the detection and assessment of vertical fractures.

40.10 Overview and magnification

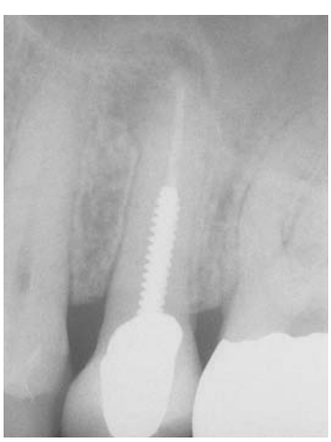
Left: Low-power view of an extracted premolar. Details of the apical anatomy are not visible.

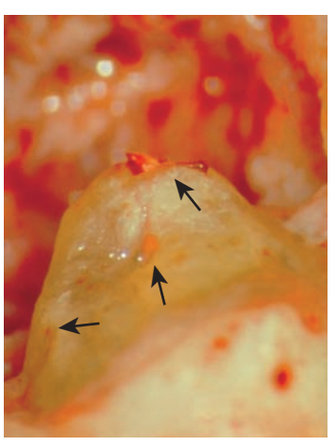
Right: High-power view (magnification ×25) of the palatal root of the same tooth with several ports of exit at the apex (arrows).

40.11 Dental microscope

Microscope in use during a surgical procedure, with a color monitor and an observation eyepiece for the dental assistant.

Left: Visualization of the light path.





40.12 Overview and magnification

Left: Radiograph of a premolar with an apical lesion.

Right: Following apical curettage, the ports of exit of the apical delta can be discerned at magnification ×25.

Flap Design and Soft-tissue Management

Use of the appropriate injection techniques should achieve an anesthetic as well as a hemostatic effect. The use of local anesthetics with a higher epinephrine concentration will reduce hemorrhage and therefore improve visibility during the surgical procedure. An epinephrine concentration of 1:50 000 is recommended.

Essentially healthy gingival (periodontal) conditions in the area of the surgical intervention are advantageous for optimal healing and minimal gingival recession. Atraumatic surgical techniques and understanding of wound healing principles will help to achieve optimal results.

Flap Design

Mucoperiosteal full-thickness flap. A mucoperiosteal flap consists of gingival mucosal tissues as well as periosteum. The critical ratio of the flap width to height should not be less then 2:1. Therefore horizontal extension of the flap may involve adjacent teeth.

Rectangular flap. A rectangular flap provides excellent access to the apical area and is raised by an intrasulcular incision combined with two vertical releasing incisions. The vertical incisions should dissect the periosteum to the bone and be placed parallel to the long axis of the tooth. This will sever the least number of blood vessels, which run vertically from the apical to the coronal region. Although the rectangular flap is the most frequently used flap, its disadvantage is the possible marginal gingival recession.

Submarginal flap (as described by Ochsenbein-Luebke). Restorations with subgingival margins are prone to recession following marginal mobilization. In such cases, instead of the intrasulcular incision, a submarginal incision can be made. The incision is placed within the attached gingiva and follows the course of the gingival margin. Importantly a width of at least 2 mm of the attached gingiva should be preserved, coronal to the horizontal incision. Therefore adequate width of attached gingiva is required. Another prerequisite is that the osseous defect should not extend to the cervical portion of the root.

Triangular flap. This variation with only one vertical, usually mesially placed releasing incision provides only limited access to apical areas. This approach can be useful for the treatment of cervical resorption, perforations in the cervical and middle sections of the root, or for the resection of rather short roots. An advantage is the possibility of extending the flap. This can be accomplished by extending the intrasulcular incision, or by adding an additional vertical releasing incision.

40.13 Anesthetic agents and injection technique

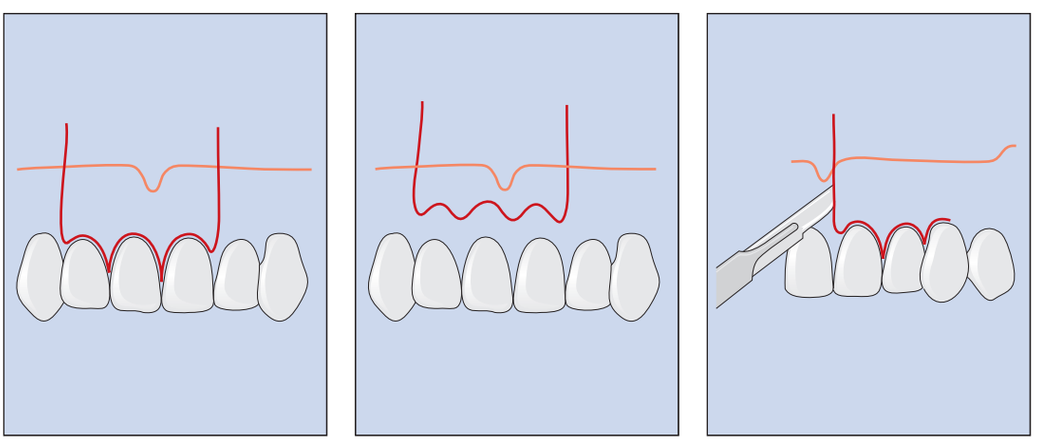
Anesthetic agents for a surgical procedure: Top carpule: Articaine forte (4%) with 1:100 000 epinephrine for anesthesia and initial hemostasis. Bottom carpule: Lidocaine (2%) with 1:50 000 epinephrine for prolonged hemostasis.

Right: Application of the anesthetic at the apical region. The entire intended flap area is perfused with anesthetic solution.

(Source: Textbook of Endodontology. Oxford: Blackwell Munksgaard, 2003.)

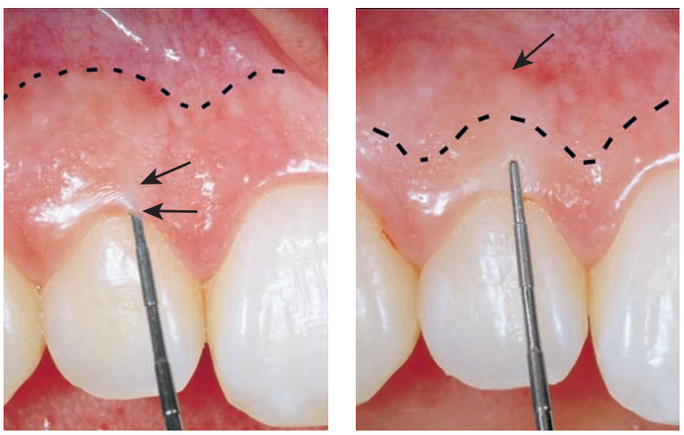
40.14 Flap design

Incision designs for a rectangular flap (left), submarginal or Ochsenbein-Luebke flap (middle), and triangular flap (right).



Papilla base flap. Complete and predictable restoration of lost interdental papillae is one of the biggest challenges. The goal of the papilla base incision is to maintain the integrity of the papillae during the healing process (Velvart, 2002). A papilla base flap consists of two vertical releasing incisions, connected by a papilla base incision.

For this procedure, a microsurgical scalpel is required. The papilla base incision requires two different incisions at the base of the papilla. The first shallow incision separates epithelium on the surface of the gingiva and connective tissue up to a depth of 1.5 mm. In the second step, the scalpel is placed at the base of the previously created incision and subsequently inclined apically, directed toward the crestal bone margin. With this second incision, a split-thickness flap is prepared in the apical third of the base of the papilla. This incision is best performed with magnification (e.g., with loupes).

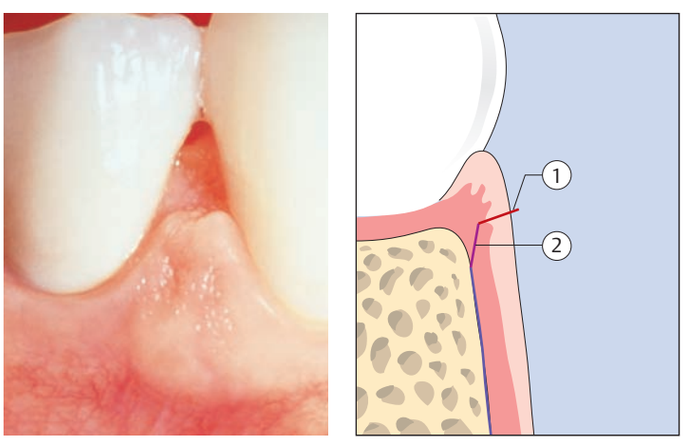


40.15 Determination of attached gingiva

Left: Probing depths. The mucogingival line is shown with dashes.

Right: Determination of the width of the attached gingiva. A submarginal incision requires at least 2 mm of attached gingival, coronal to the incision line.

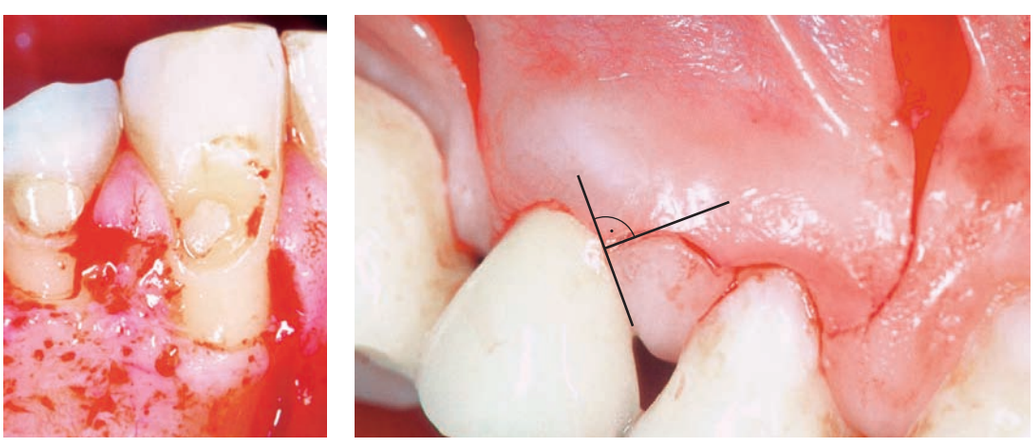
(Source: Textbook of Endodontology. Oxford: Blackwell Munksgaard, 2003.)



40.16 Unfavorable papilla healing and how to prevent it

Left: Unfavorable healing result with loss of the papilla height, following mobilization of the papilla during flap reflection.

Right: Two incisions to raise a papilla base flap:
1: The initial incision is placed through the epithelium to a depth of 1.5 mm.
2: The second incision creates the split-thickness flap down to the alveolar crest.



40.17 Course of the incision

Left: Clinical view immediately following mobilization of the soft-tissue flap. Note the split-thickness flap in the area of the base of the papilla and the full mucoperiosteal flap apical to the alveolar crest.

Right: Course of the incision for a papilla base flap. The papilla itself is not elevated or mobilized. The incision should start and end perpendicular to the gingival margin (black lines).

(Source: Velvart P. Papilla based incision. Int Endod J 2002;35:432–460.)

Semilunar flap. The semilunar flap, described originally by Partsch, was once popular but is now considered outdated. The incision in the mucosa permits only limited access, and is associated with a high risk of placing the incision over the osseous defect. Due to the microarchitecture of the mucosa, numerous blood vessels, and muscle attachments, it is often difficult to reapproximate the wound margins without tension, and this frequently results in impaired healing and scar formation.

Mobilization and Retraction

Working from the vertical incision, the mucoperiosteal flap is carefully raised from its osseous base, using a sharp elevator. Tearing and pulling on the flap should be avoided. In addition, the retractor should be placed securely on bone and not traumatize the soft tissue. The preparation of a small groove in the bone will enable secure positioning of the retractor and protect the mobilized tissue.

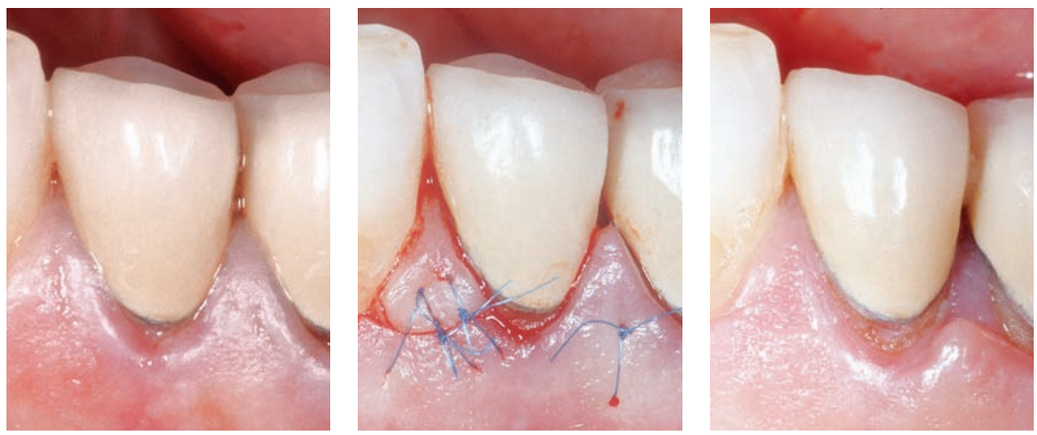
40.18 Comparison of papilla healing with different flap designs

Left: Preoperative view

Middle: Immediate postoperative image of sutures after full papilla mobilization (distal) versus papilla base incision (mesial).

Right: Healing result at 3 months. Note the pronounced papillary recession distally.

(Source: Velvart P. Comparison of papilla healing. Int Endod J 2003;36:653–659.)

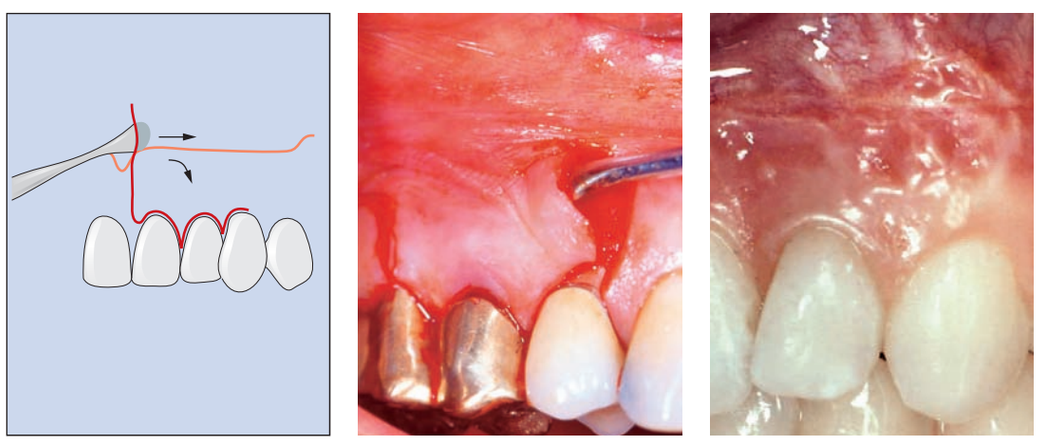


40.19 Mobilization of the flap

Left: Schematic depiction of flap reflection.

Middle: The soft-tissue flap is mobilized from the vertical releasing incision.

Right: Scar formation within the mucosa following three apicectomies. The appearance of the scar indicates the previous use of a semilunar flap.

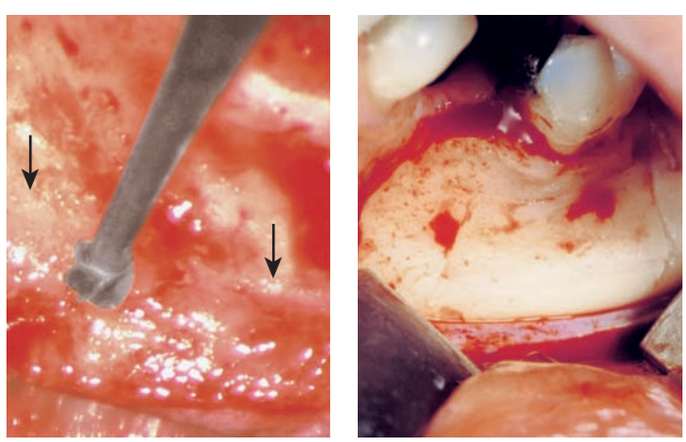


40.20 Tissue retraction

Left: Preparation of a small groove using a small round bur for secure placement of the tissue retractor.

Right: Retractors in position following flap reflection during an apicectomy on a mandibular molar.

(Source: Textbook of Endodontology. Oxford: Blackwell Munksgaard, 2003.)

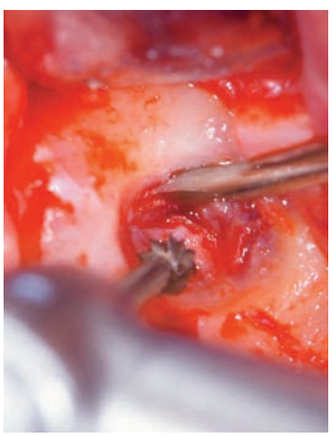


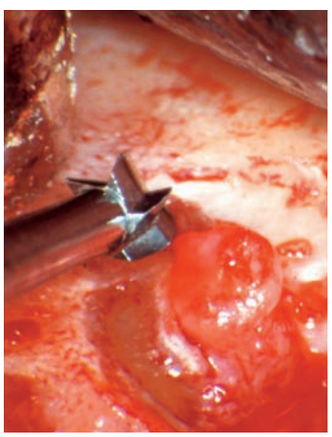
Root Resection (Apicectomy)

Usually a small area of osseous access is achieved using a bone drill with copious saline cooling, working toward the apical area. When the apical defect is exposed, the granulation tissue should be removed to allow evaluation of the apical root anatomy.

The apicectomy can now be carried out. In order to include all ramifications of the root canal system in the apical region, the root tip should be resected 3 mm from the apex. A resection angle of 0–10° is best. This minimizes the number of dentinal tubules reaching the resection surface from the unprepared root canal space. The earlier recommended resection angle of 45° is no longer preferred except in rare situations with limited access to deeply located roots in the jaws.

Using narrow, long diamond burs, it is possible to completely resect the root even deep within bone (lingual or palatal).

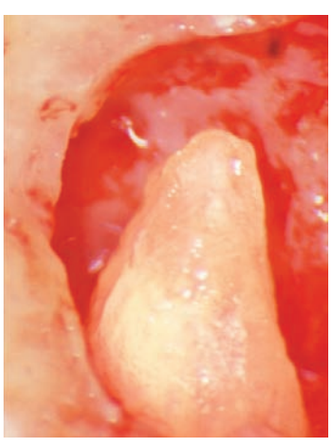


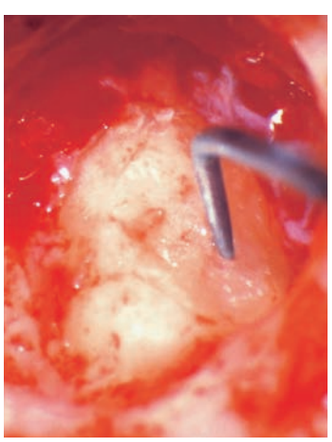


40.21 Ostectomy

Left: Removal of bone using a round bur in the maxillary premolar region. Note the protection of the sinus membrane with a sinus elevator.

Right: Exposure of the apical area.

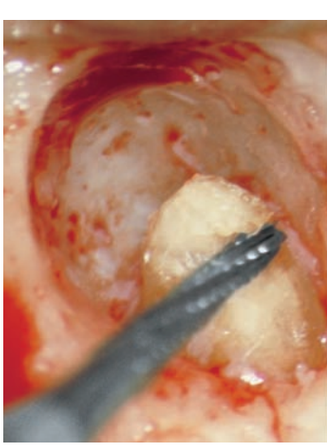


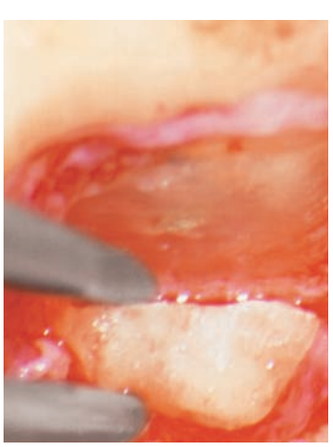


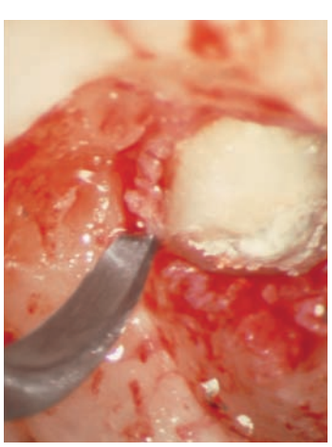
40.22 Apical region

Left: View of the apex following curettage of the lesion.

Right: Demonstration of a port of exit in a maxillary premolar.







40.23 Resection

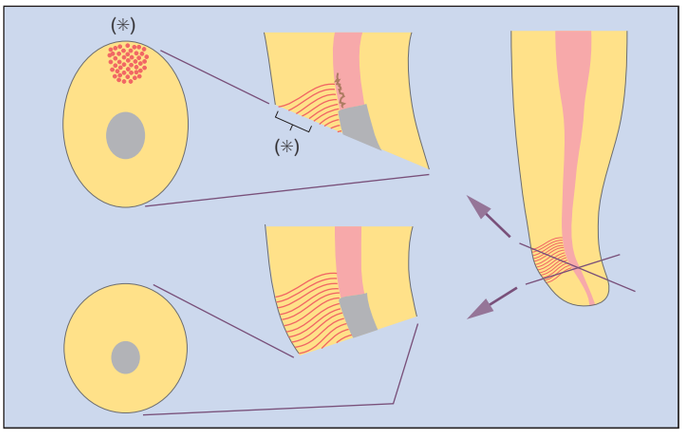
Left: Resection of the apex using a fissure bur.

Middle: Removal of the resected root fragment using microforceps.

Right: Curettage of granulation tissue with a scaler.

40.24 Angle of resection

Influence of the angle of resection on the penetration of toxins from the root canal through the dentinal tubules (*) onto the resected surface. In the presence of inadequate depth of preparation in combination with an acute bevel, bacterial products can pass through this pathway and maintain the inflammatory process.

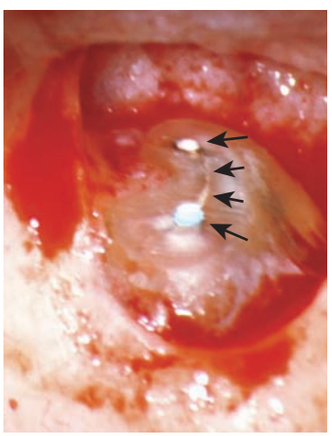


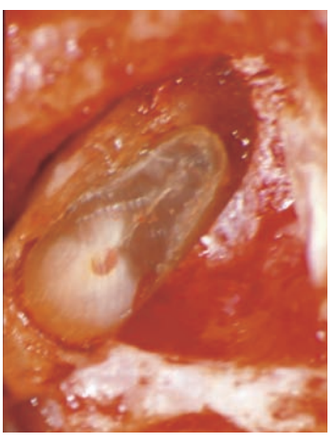
40.25 Evaluation of the resection surface I

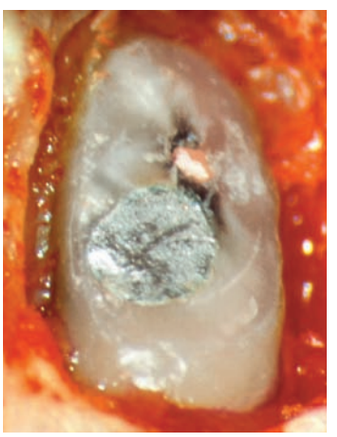
Left: Resection surface of a maxillary premolar. Besides two root canals (long arrows), a fine isthmus (short arrows) is clearly visible.

Middle: Mesial root of a maxillary molar. Note the untreated second mesiobuccal canal.

Right: Failure following retrograde closure with amalgam. The procedure was obviously insufficient to eliminate the cause of the pathologic process (necrotic material adjacent to the root canal filling).



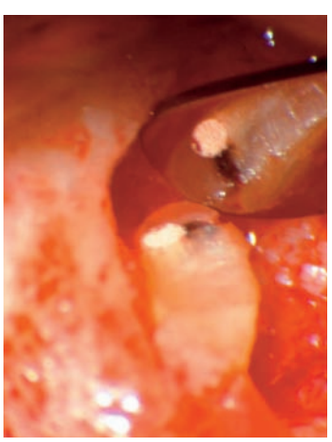


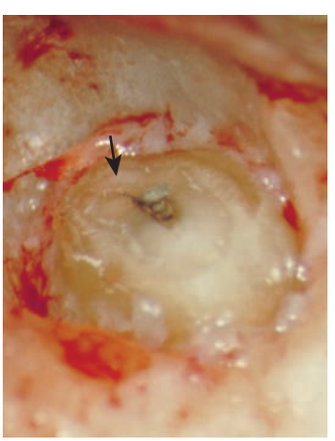


40.26 Evaluation of the resection surface II

Left: Clinical view following resection of the root apex. Necrotic material is visible lateral to the root canal filling.

Right: A lateral canal has been exposed (arrow) during the resection procedure and must be treated.

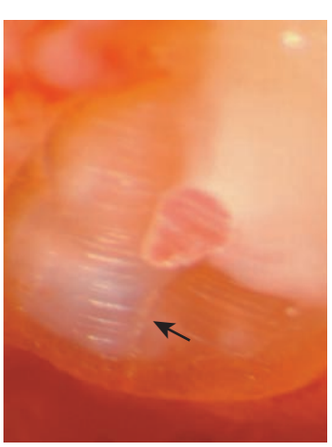


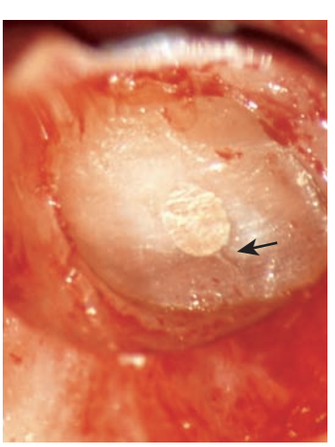


40.27 Cracks and fractures

Examples of a fine crack in the apical portion of the root (arrow).

(Source: Velvart P. Schweiz Monatsschr Zahnmed 1997;107:969–978.)



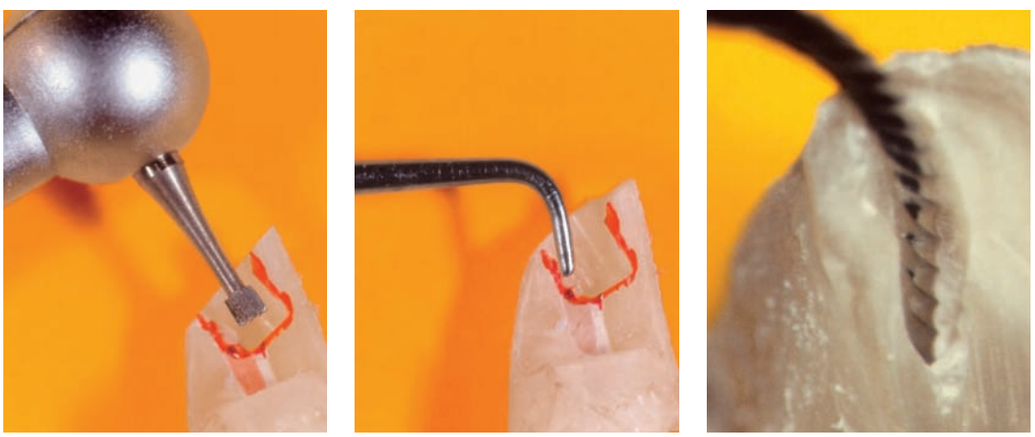


Retrograde Preparation

The preparation is carried out using ultrasonically powered devices. The working tips are either prefabricated with various shapes, surface coatings, and bends, or individually bent files can be used. Different tips are available for the anterior and posterior regions of the oral cavity.

The ultrasonic energy causes the tip to vibrate, which removes both hard and soft tissues in the root canal. These fine instruments permit access to the root canal from the retrograde approach with direct vision and require a relatively small osseous access. Using a gentle "up and down" motion, root canals and isthmus formations can be widened to a depth of at least 3–4 mm, and root canal filling material can be removed as well. Application of methylene blue stain is helpful in visualizing root canal complexities or cracks.

Studies have shown that ultrasonic preparation is superior to conventional preparation with round burs in a micro-handpiece. Ultrasonic preparation will result in cleaner, more parallel, and deeper preparation. The drawback of ultrasonics is the reported risk of microcracks and fractures. The use of ultrasonically energized files requires much lower energy than the stiff, prefabricated tips. They are resilient when tilted, which minimizes the wedging forces.

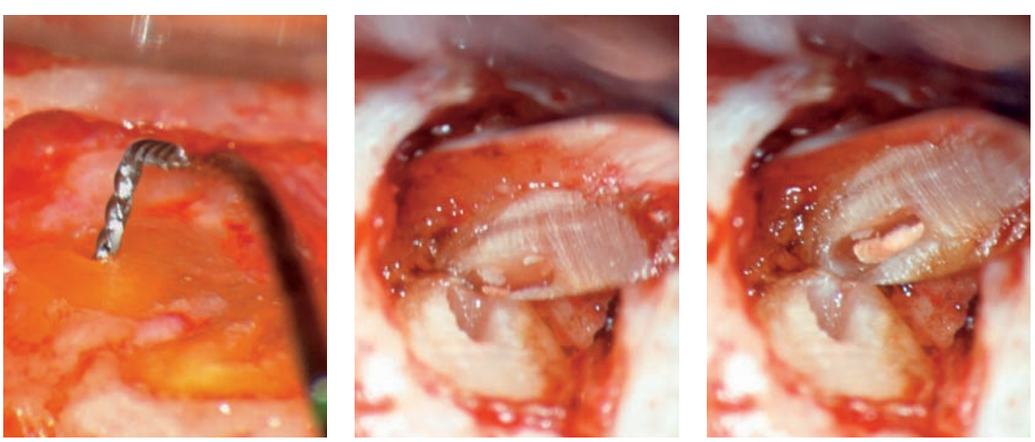


40.28 Retrograde preparation instruments

Left: The micro-handpiece. The use of a bur results in overextension of the retrograde cavity.

Middle: Ultrasonic tips allow access to areas of the canal previously difficult to access.

Right: Use of an ultrasonic file for retrograde cleansing of the root canal.

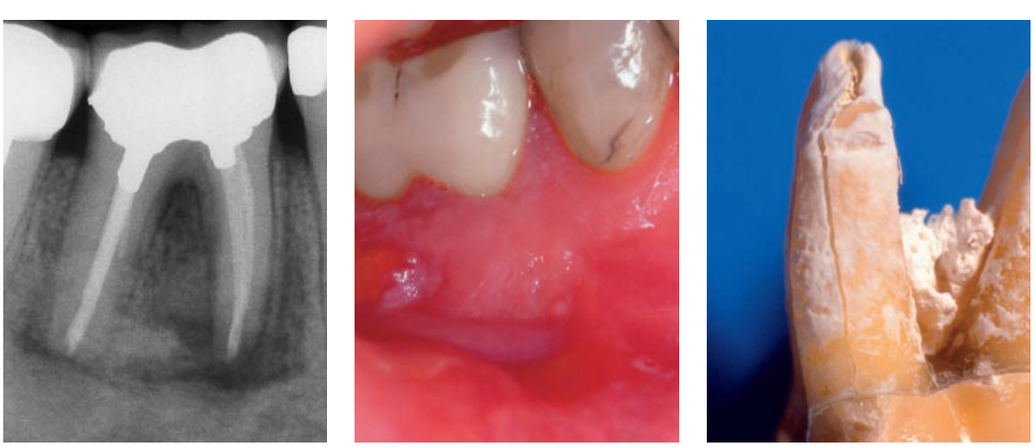


40.29 Ultrasonically energized files

Left: An ultrasonic file being used on a maxillary molar. Despite the deep position of the palatal root in the maxilla, instrumentation can be carried out under optimal direct vision.

Middle: Evaluation of the preparation following retrograde preparation in a maxillary premolar.

Right: Circumferential checking of the cavity with a micromirror. The root canal filling remaining in the palatal aspect is visible.



40.30 Failure following retrograde therapy

Left: The radiograph reveals apparently adequate retrograde preparation and apical obturation.

Middle: Fistula formation 1 month following apicectomy.

Right: A vertical fracture was the reason for the failure.

Retrograde Filling

The goal of the retrograde filling is to seal the prepared cavity to prevent leakage of tissue fluids to the remainder of the root canal space and to prevent the exchange of bacterial products, which may result from such leakage. Unfortunately there is no obturation material that fulfills all the requirements for an ideal sealing agent (Chong and Pitt Ford, 2005). Most filling materials available today need to be applied and used under optimal (dry) conditions. The cavity must be thoroughly irrigated and carefully dried prior to obturation (e.g., using the multifunction attachment described by Stropko).

Additional removal of the smear layer using citric acid (10%) or phosphoric acid (37%) remains controversial.

Various materials have been discussed and are used today. These include modified zinc oxide eugenol cement, mineral trioxide aggregate (MTA), composite resin, Diaket (3M ESPE, Seefeld, Germany) and glass ionomer cement.

Zinc Oxide Eugenol Cements

The best known examples of zinc oxide eugenol cements are SuperEBA (Bosworth, IL, USA) and IRM (Dentsply, PA, USA). In SuperEBA, eugenol is replaced for the most part by ethoxybenzoic

40.31 Drying the cavity

Left: Special attachment for easy drying of the apical cavity prior to placement of the filling material.

Right: Drying the cavity using a thin needle (0.4 mm) in a maxillary molar.

Caution: Pressurized air! Directing pressurized air into the surrounding trabecular bone must be avoided at all costs!

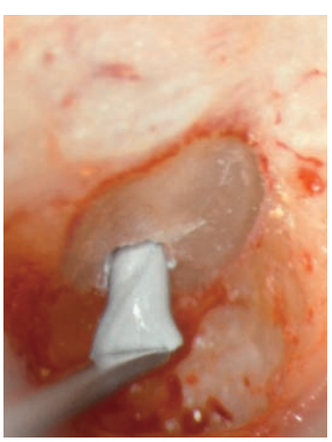
40.32 Requirements for an ideal retrograde filling material

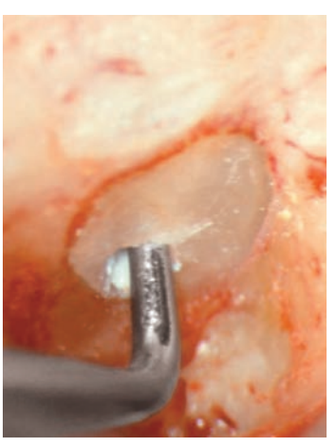
Dimensional stability (also in the presence of moisture)
Biocompatibility
Radiopacity
Ease of manipulation and application
Antibacterial property
Permits bonding to the dentin surface
Enhances regeneration of periodontal tissue
No staining or discoloration of surrounding tissues

40.33 Application of SuperEBA

Left: Application of SuperEBA with a microspatula in a lower premolar.

Right: Condensation of material with a plugger.

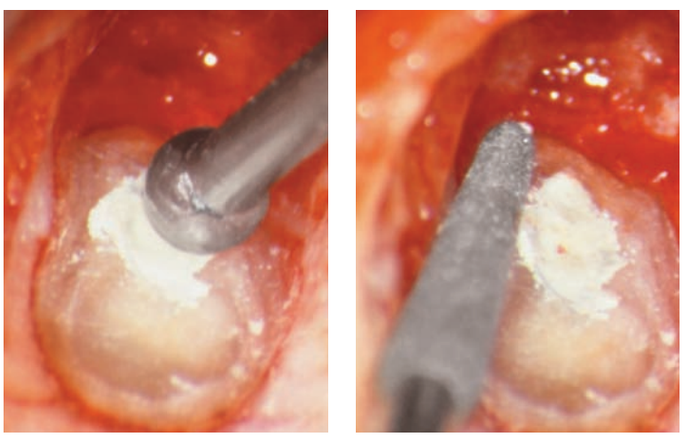




acid (ratio 2:1): the powder in the IRM preparation contains a polymer to enhance the mechanical properties. The good sealing characteristics, low solubility, and excellent handling properties are the main advantages of both EBA and IRM.

To minimize the initial toxic reaction to eugenol a very dry mixture should be used. A high powder to liquid ratio is recommended. The material is mixed on a glass slab and rolled into small 2–3-mm cones, placed into the prepared cavity with a microspatula, and subsequently condensed using a small, angulated plugger. Excess material is removed with a carver. The zinc oxide eugenol cement sets rapidly when exposed to moisture after compaction. The resected root surface is polished with a finishing diamond and any excess filling material is removed. After setting, the material seems to cause little irritation in the surrounding periradicular tissues.

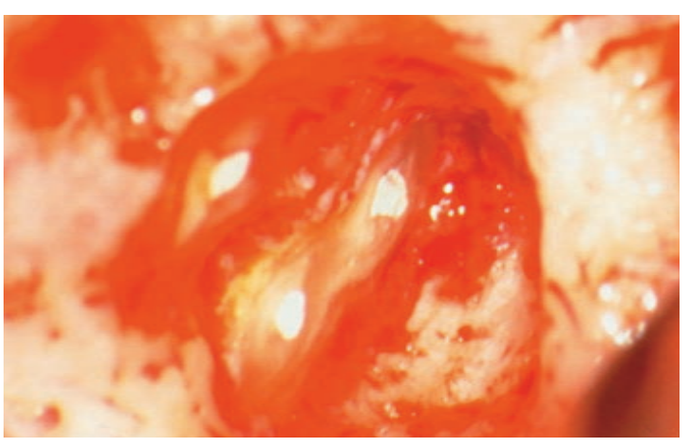
Following final irrigation of the osseous cavity, the neighboring structures (exposed bony cavity, internal surface of the mucoperiosteal flap) should be carefully inspected at higher magnification. The osseous walls are cleaned using a sharp spoon excavator, and any remaining hemorrhage-preventing agents should be removed. Filling the osseous lesion with bone replacement materials or the use of a membrane is usually not necessary.



40.34 Adaptation of the filling material

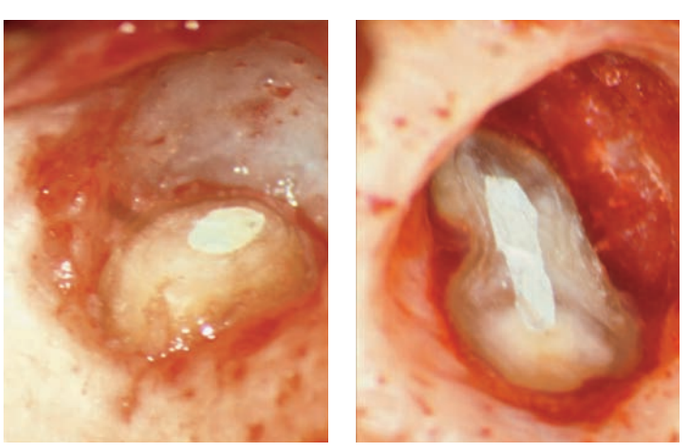
Left: Adaptation of the filling material using a ball burnisher.

Right: After setting of the cement, the excess material is removed and the resection surface is polished using a finishing diamond.



40.35 Retrograde obturation I

View of a retrograde procedure, sealed with SuperEBA in a maxillary molar.



40.36 Retrograde obturation II

Clinical view following retrograde filling with SuperEBA in an anterior tooth (left) and a premolar (right).

Mineral Trioxide Aggregate (MTA)

MTA is a highly promising new cement. The powder consists of fine hydrophilic particles that, when mixed with water, set in 2.75 hours. During setting there is a pH increase of up to 10.2–12.5, which has a certain bacteriostatic effect.

Various studies have shown MTA to seal well and display good biocompatibility. The formation of osseous hard tissue and cementogenesis is enhanced by the presence of MTA. ProRoot (Dentsply) was the first commercially available MTA product, and the most thoroughly studied one. It was first introduced as a gray powder, and later as a white powder without tetracalcium aluminum ferrite. Its radiopacity is comparable with gutta-percha.

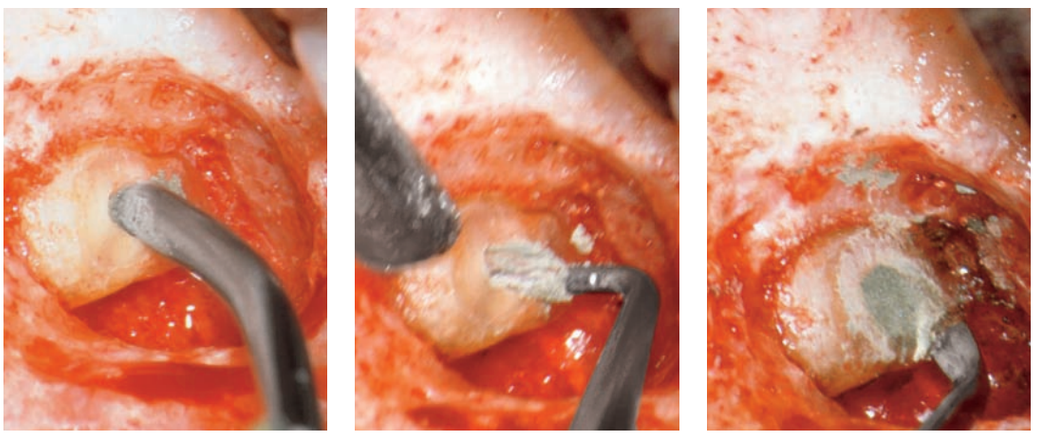
The manufacturer's recommendations concerning the mixing of MTA should be closely adhered to. However the material is difficult to handle because of its consistency and requires some practice. Various application instruments and procedures have been suggested.

40.37 Use of MTA

Left: Placement of MTA using a syringe applicator.

Middle: Condensation of MTA with a plugger.

Right: Removal of excess material using a microexcavator.

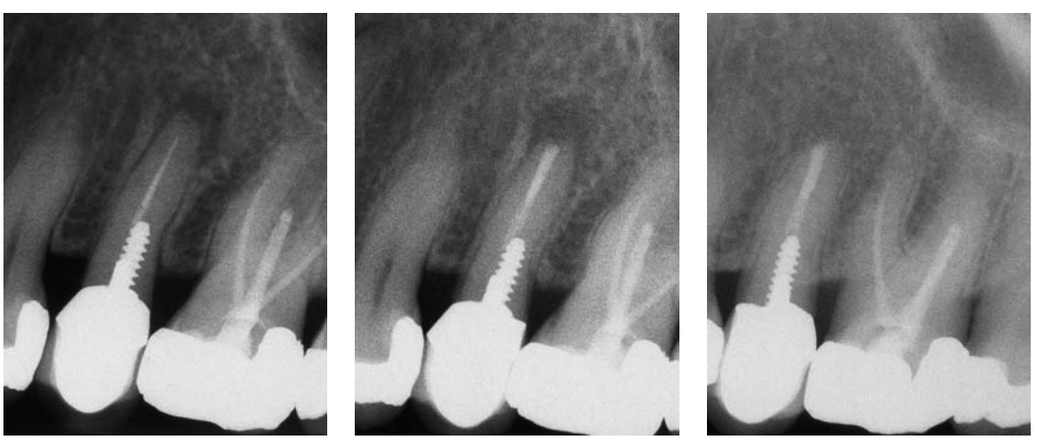


40.38 Retrograde therapy in teeth with post and core I

Left: Apical lesion on a maxillary premolar.

Middle: Postoperative radiograph following retrograde preparation and placement of SuperEBA.

Right: Complete healing of the lesion 2 years after apicectomy.



Other Materials

Retroplast (Retroplast Trading ApS, Denmark) is a composite material combined with a dentin adhesive system (Gluma); it is not yet in wide use but clinical studies have shown it to be a material to consider. It consists of two components (BisGMA + TEGDMA) and hardens autocatalytically. A prerequisite is application of adhesive and composite under dry conditions. Because the application of the adhesive to the canal walls in a deep retrograde cavity is often clinically difficult, a concave preparation of the resection surfaces should be carried out. The subsequent sealing of the entire resection surface will also close any dentinal tubules and lateral canals.

Diaket in a powder liquid ratio of 2:1 when used as a retrograde filling material exhibits favorable characteristics, although the number of studies is limited in comparison to outcome data on zinc oxide eugenol cements or MTA. The potential of glass ionomer cements is controversial. Amalgam as a retrograde filling material is today considered obsolete.

In certain situations, gutta-percha is recommended as part of the obturation filling. As stated earlier endodontic orthograde treatment is the first choice when apical pathology is present. However, in certain situations, when canals are hard to find and substantial amounts of build-up and dentin have to be removed, jeopardizing the retention of large prosthetic reconstruction, primary surgical treatment might be considered. In such situations the pulp space is instrumented from the retrograde approach using ultrasonic files and gutta-percha points or warmed gutta-percha in conjunction with a sealer for obturation of the deeper segments of the canal. The most apical portion of the canal is generally closed with MTA.

In the case described here, abutment tooth 13 developed a periapical lesion after an esthetically and functionally perfect but extensive restoration. Considering the long and presumably thin abutment, a surgical approach was selected in order to avoid loss of retention on the abutment with subsequent failure of the entire restoration through an orthograde access.

40.39 Retrograde therapy in teeth with post and core II

Left: Apical lesion on a mandibular molar.

Middle: Postoperative radiograph following retrograde filling using MTA.

Right: Complete healing of the lesion 1.5 years after apicectomy.

40.40 Primary retrograde therapy

Left: Apical lesion on an abutment tooth with an intact multiunit bridge. The orthograde access cavity preparation could result in loss of retention and thereby endanger the survival of the entire bridge construction.

Middle: Retrograde instrumentation of the root canal and filling with gutta-percha and MTA.

Right: Healing, 2 years after apicectomy.

Wound Closure and Initial Healing

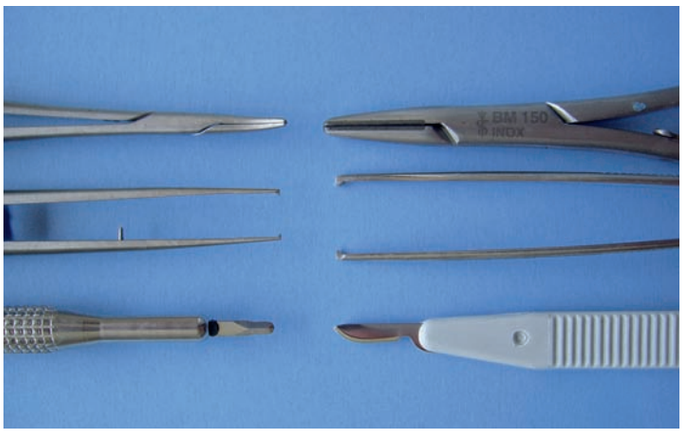
The healing of oral tissues generally progresses quickly and without complication when basic biologic principles are respected and followed. Repositioning flaps in their original position with margins closely approximated by careful suturing will result in rapid healing.

The flap must be kept moist during the entire surgical procedure to prevent shrinkage, which would prevent tension-free readaptation of the wound margins. Compression of the adapted flap with sterile gauze prior and after suturing prevents the formation of a blood clot and hematoma, thereby promoting the healing process. Wound margins under any tension can lead to dehiscence, scar formation, and delayed healing.

The wound-healing process consists of four stages, which are not distinctly separated from each other. These are: clotting and inflammation; epithelial healing; connective-tissue healing; and finally the maturation and remodeling process.

40.41 Comparison of instruments

Microinstruments are shown on the left and conventional (delicate) instruments on the right.



40.42 Schematic phases of wound healing

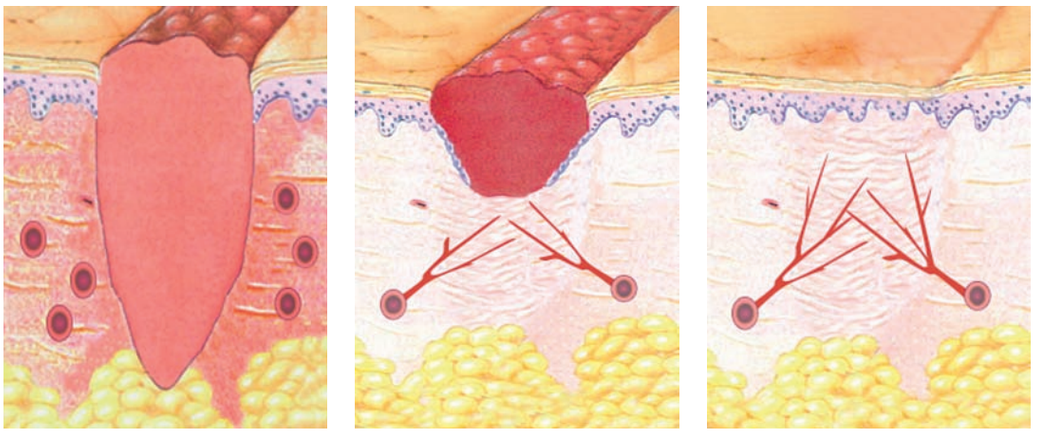
Schematic phases of wound healing, following a full-thickness flap.

Left: Blood clot (0–30 minutes), followed by inflammation (0–5 days).

Middle: Repair and remodeling (4–16 days).

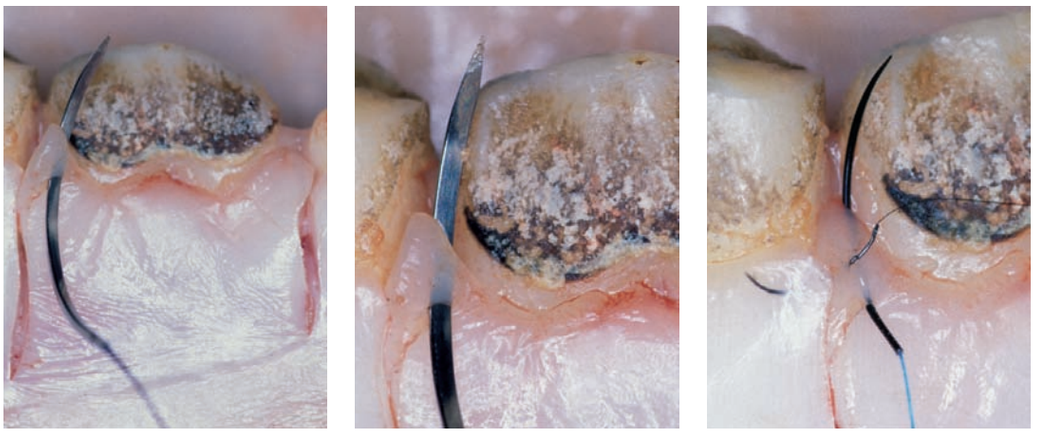
Right: Healing after 6 weeks.

(Source: Häkkinen I, Kitto VJ, Larjava H. Cell biology of gingival wound healing. J Periodontol 2000;24: 127–152).



40.43 Needles and suture material

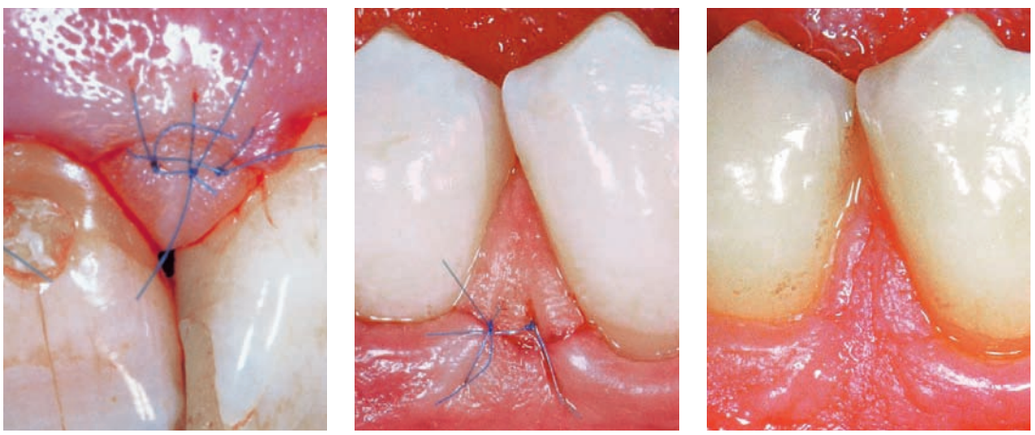
Use of a 4/0 needle on an interdental papilla in an animal in an experimental study. View without (left) and with (middle) a 5x magnification. Rather severe trauma is obvious; even the passage of the needle through the flap almost severs the papilla. With the use of microsutures of size 7–0 for the vertical incision, as well as 8–0 for the horizontal fixation of the wound margins, the tissue is subjected only to minimal tissue trauma, because of the extremely delicate dimensions of the suture material (right).



Suturing

Atraumatic sutures should be used in sizes 6/0 or thinner. Although fine in size, the needle should preferably brigid and a 3/8 circle with a sharp, pointed triangular cross section. The needle length can be a problem in papilla closure, because fine suture sizes come with rather short needles. The comfortable needle length for interproximal suturing is 12 mm. Nonresorbable suturing material with a smooth surface is preferred. Although the suturing techniques vary according to flap design, usually single sutures are applied to hold the wound margins in place during the initial healing phase. Vertical mattress sutures can be used to reapproximate the interdental papilla (size 6/0). Special attention must be given to repositioning of wound margins in the papilla base flap with suture material not exceeding 7/0 or 8/0.

If wound healing is uneventful, the sutures can be removed within 3–5 days. By this time an epithelial lining will have formed, which protects the connective tissue from irritants from the oral cavity.

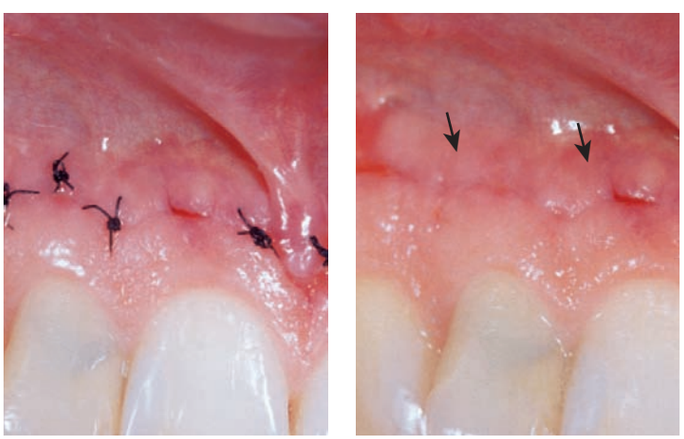


40.44 Papilla base flap

Left: Wound closure of a papilla base flap using three polypropylene 7–0 sutures.

Middle: Condition immediately following the surgical procedure.

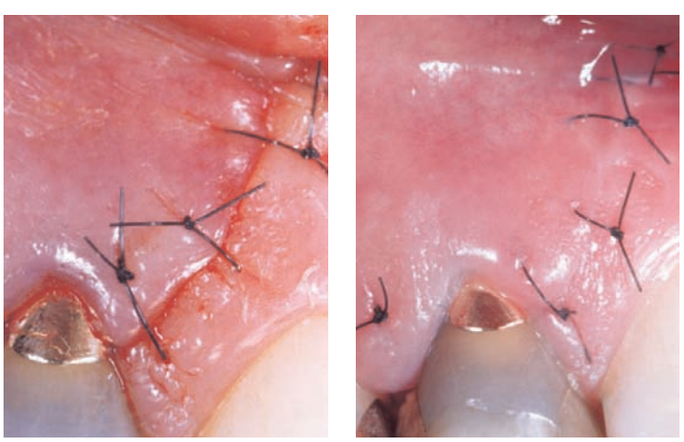
Right: Excellent healing after 1 month. The incision line can hardly be discerned.



40.45 Submarginal flap, importance of perfect tissue adaptation

Submarginal flap, sutured with size 6–0 material immediately before (left) and immediately after (right) suture removal. Note the nicely healed area (arrows) in addition to areas of dehiscence that resulted from inadequate flap adaptation.

(Source: Velvart, P, Peters CL. Soft tissue management in endodontic surgery. J Endod 2005;31:4–16.)



40.46 Vertical releasing incision

Optimally adapted vertical releasing incision immediately postoperative (left) as well as 4 days later (right) prior to suture removal. Good tissue adaptation in combination with atraumatic handling of the tissues resulted in optimal healing.

(Source: Velvart, P, Peters CL, Peters OA. Soft tissue management in endodontic surgery. Endodontic Topics 2005;11:179–195.)

Prognosis

The outcome following apicectomy is determined primarily by the osseous healing of the bony lesion, which can be followed over time radiographically. There are varying criteria for "successful" apical surgery (different inclusion factors, follow-up periods, evaluation criteria, and observer variations), therefore comparison and general conclusions are difficult. Some studies have ranked only fully healed osseous defects as "healed," whereas others have classified cases as "successful" if the apical lesion diminished in size ("healing") as long as the tooth was clinically symptom-free during the observation period.

From the perspective of evidence-based dentistry, according to Friedman (2005) and Mead (2005) the number of relevant clinical studies published since 1970 dealing with prognosis of apicectomy is reduced to eight studies with an evidence grade of 4 (5 being the highest evidence grade).

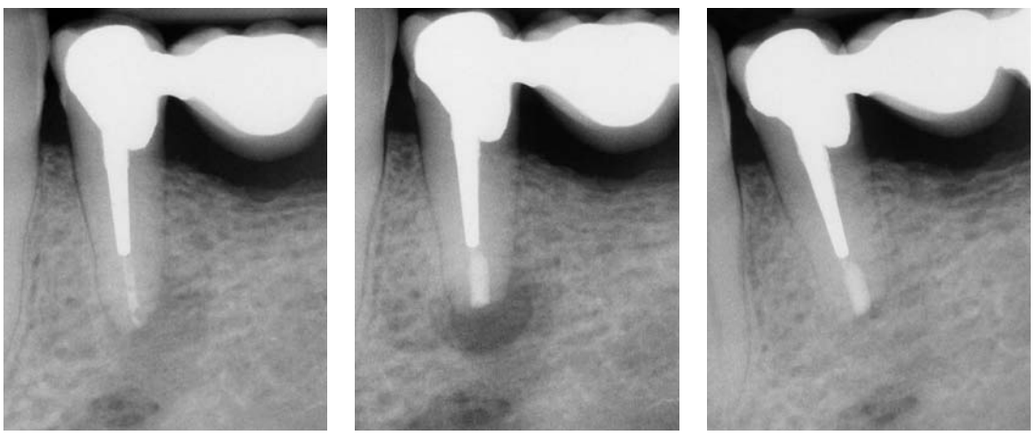
Various *preoperative* factors can affect the probability of success: In teeth with small periapical lesions and massive over- or underfilled root canals, the prognosis is better, but becomes less favorable with repeated surgical intervention. With regard to the *intraoperative* factors, the retro-filling procedure and the type of filling materials may promise a more favorable prognosis, while the *postoperative* use of antibiotics has no effect whatsoever (Friedman, 2005).

40.47 Successful healing I

Left: Large lesion at the apex of a mandibular premolar. Note the close relation to the mental foramen.

Middle: Postoperative radiograph after retrograde use of MTA.

Right: Complete healing of the lesion 2.5 years following apicectomy.



40.48 Successful healing II

Left: Apical lesion on a maxillary premolar with a post and full crown restoration.

Middle: Postoperative radiograph following retrograde closure using MTA.

Right: Osseous healing of the apical defect 1 year following apicectomy.

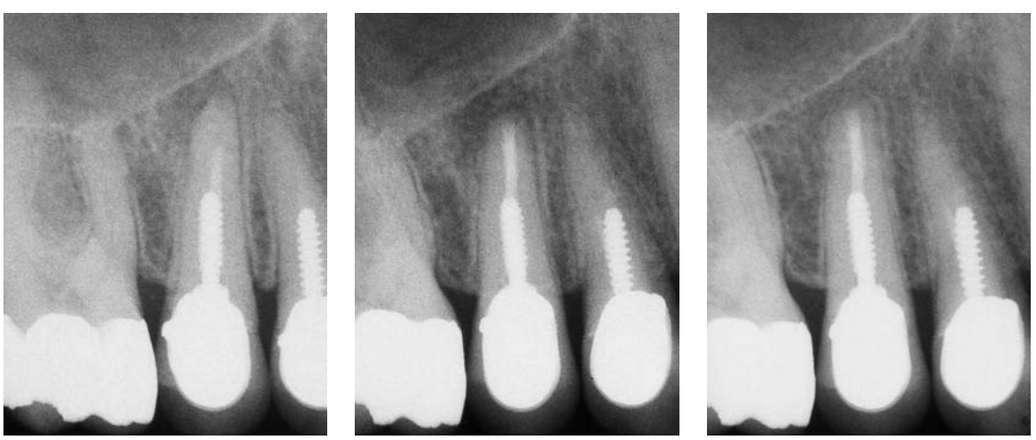


Figure 40.49 presents the results of the eight studies mentioned above. The category "functional" consists of the sum of the two categories, "healed" and "healing," unless otherwise noted. With these limited data from evidence-based studies, several questions remain unanswered, especially those regarding the significance of potential pre-, intra-, and postoperative influencing factors.

Therefore, it is difficult to draw strong conclusions with regard to the currently used retrograde filling materials on the basis of the available data. Chong et al. (2003) reported that the rate of healing after use of MTA was 92% ("complete and incomplete healing"), and with IRM 87%, 2 years following treatment. The use of Retroplast proved to be a valid alternative, with a healing rate of 73%–90% (Jensen et al., 2002).

Undoubtedly it seems likely that modern surgical techniques (operating microscope, ultrasonically energized preparation, microsurgical instrumentarium) increase the rate of success. However, there is still a lack of evidence-based clinical studies with sufficiently large numbers of cases and sufficiently long observation periods.

From a prognostic viewpoint, a comparison will be made of apicectomy and a dental implant as an alternative treatment. In the implantology literature, the parameter for measuring success is usually "survival." Conclusions drawn by comparing survival rates of implants with the success rates shown in Figure 40.49 should be treated with great caution. Survival measures only the timespan until the implant is lost, regardless of whether biologic (peri-implantitis) or technical complications occurred during the observation period. On the other hand, the success rate in endodontic surgery is based on the number of successful cases in comparison with the total number of treated cases, without any direct regard to time. For this reason, the evaluation of an individual situation should be based on various case-specific factors —such as local conditions, or the expertise of the clinician—rather than using "average" values.

It remains to be seen whether the currently available clinical data on the prognosis of apicectomy or implantology can be directly applied to clinical practice. These studies were for the most part carried out in university clinic settings, under ideal conditions, and, as such, they document the potential of a specific therapeutic method.

Study	Δt* (years)	Number of cases	Recall rate (%)	"Healed" (%)	"Healing" (%)	"Functional" (%)
Zetterqvist[1] et al. 1991	1	105	100	61	31	≥ 92
Jesslén[1] et al. 1995	5	93	94	59	2	≥ 87
Danin[1] et al. 1999	1	10	100	50	50	—
Kvist u. Reit[1, 2] 1999	4	45	100	60	—	—
Zuolo[2] et al. 2000	1–4	102	96	91	—	—
Rahbaran[2] et al. 2001	≥ 4	129	61	37	33	≥ 80
Jensen[2] et al. 2002	1	60[Rp]	91	73	17	≥ 90
Chong[1, 2] et al. 2003	2	108	59	90	6	≥ 96

40.49 Comparison of prognostic studies dealing with apicectomy

*Observation time; [1] according to Mead et al. 2005; [2] according to Friedman 2005; [Rp] only retroplast

41 Traumatology

Epidemiologic studies have shown that one in two children experiences dental trauma, usually between the ages of 8 and 12. For a determination of the extent of the injury, as well as for planning appropriate therapy, a complete diagnostic examination is critical. The initial clinical examination must include determination of tooth mobility and displacement, careful periodontal probing, assessment of soft-tissue injury, as well as percussion and sensitivity tests. Radiographic examination is essential.

As trauma often leads to multiple injuries, less obvious injuries on the tooth in question and the adjacent teeth or antagonists should not be overlooked. Also, for forensic reasons, it is necessary to examine the alveolar processes, the mandible, and midface for signs of possible fracture and other serious injuries in the head/neck region.

Complete and clearly documented clinical findings will help to reach an accurate diagnosis and determine any subsequent necessary treatment.

The consequences of dental trauma are many, presenting as injury to various structures of the teeth or surrounding tissues. Especially in complex cases, restorative, endodontic, and periodontal aspects must be all be taken into consideration during treatment planning. In addition, since mainly children and young adults are affected by dental trauma, treatment must avoid negative effects on further jaw growth and take into consideration the life expectancy of the patient.

Emergency treatment often includes simple measures such as splinting in cases of dislocation, or covering exposed dentin in cases of crown fracture (Andreasen et al., 2007).

However, even the best treatment cannot completely rule out the possibility of late sequelae of trauma, and a regular follow-up regimen will ensure timely detection and treatment.

The prognosis in cases of dental trauma depends on a myriad of factors. The prognosis is often favorable if adequate therapeutic intervention is performed in time. Establishing the prognosis is more difficult if treatment is delayed or not carried out properly. In most trauma cases involving children and young adults, the main objective is the retention of the affected tooth until the patient is of an age when a dental implant would be feasible.

In cases of severely compromised teeth, consideration should be given as to whether it will be prudent to attempt to preserve a tooth with a questionable prognosis, or whether alternative treatment methods are more suitable. Thus in the case of young patients, orthodontic treatment should not be disregarded, and collaboration with an orthodontist is recommended. In some cases, tooth transplantation offers an alternative biologic approach to replacement of untreatable traumatized teeth (Lang et al., 2003).

Classification

According to the most current World Health Organization classification (WHO 2006), dental traumas are classified as fractures and dislocation injuries. The much-used term "luxation injury" implies the presence of a joint, and is therefore not accurate. Fractures are classified according to their localization, whereas dislocation injuries are classified according to the extent and direction of the trauma-induced dislocation of the tooth from its original position in the dental arch.

The maxillary central incisors are the teeth most often affected by dental trauma within the permanent dentition (ca. 60%), followed by the maxillary lateral incisors (ca. 22%). Mandibular anterior teeth are relatively seldom involved (central incisors 7.7%, lateral incisors 4.6%) (Borum and Andreasen, 2001).

Whereas in the permanent dentition, tooth fractures are the predominant result of trauma, in the primary dentition, because of the more elastic structure of the alveolar process in young children, dislocation injuries are more frequently observed (Schatz and Joho, 1994).

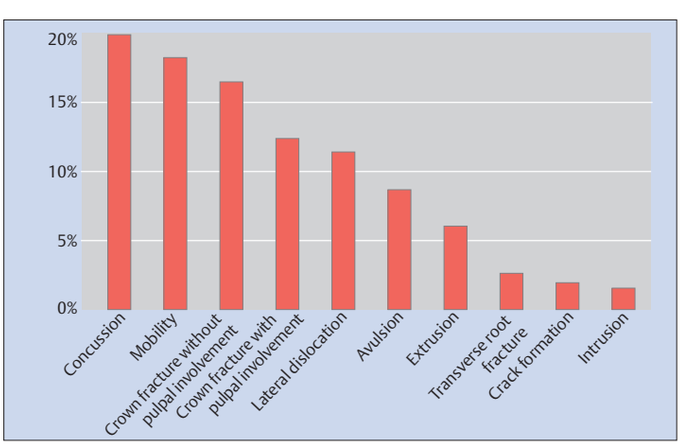
41.1 Classification of dental trauma

Frequently occurring findings in various types of injury.

Fracture	Clinical finding
Enamel crack infraction	Visible crack in the enamel without substance loss
Crown fracture (with or without pulpal involvement)	Enamel or enamel-dentin fracture with possible pulp exposure
Crown/root fracture (with and without pulp exposure)	Mobile crown fragment, often attached to the gingiva
	Not always with pulpal involvement
Transverse root fracture	Horizontal or oblique fracture of the root
	Increased mobility of the crown fragments, possibly with dislocation
	Depending on the location of the fracture line, communication with the oral cavity is possible via the gingival sulcus
Dislocation	**Findings**
Concussion	Sensitive to touch
	No increased mobility
Mobility	Sensitive to touch
	Increased mobility
	Possible hemorrhage from the gingival sulcus
Lateral dislocation	Dislocation usually in the lingual direction
	Often tooth wedged in this position, without sensitivity to percussion and a metallic percussion sound
Extrusion	Tooth appears elongated with increased mobility
Intrusion	Tooth appears shortened
	Metallic percussion sound due to wedging within the alveolar bone
Avulsion	Complete luxation of the tooth from its socket

41.2 Frequency of traumatic dental injuries

Frequency of various types of dental trauma in the permanent dentition (Borum and Andreasen, 2001).



Crown Fractures without Pulpal Involvement

Most crown fractures result in dentin exposure. In order to avoid the high risk of infection of the endodontic system via the open dentinal tubules, all emergency treatment must include coverage of exposed dentin (Andreasen et al., 2007). Ideally a flowable composite should be bonded to the dentin surface. A definitive, and possibly time-consuming, restoration can be carried out at a later date. To restore function and esthetics, it may be possible to reattach the fractured tooth fragment using an adhesive. The long-term success rate of reattached fractured tooth fragments, as reported in the literature, is 25% at 7.5 years (Andreasen et al., 1995). Extension of the adhesive surface through preparations such as enamel beveling will improve the adhesion (Reis et al., 2001).

A tooth fragment that has been left to dry for an extended period will become dehydrated, which can compromise the esthetic results and bond strength. When the trauma involves multiple or missing tooth fragments, or if these are difficult or impossible to reattach, current composite resin restorative materials provide excellent possibilities for immediate restorative treatment. Indirect ceramic restorations are more invasive and should be restricted to adult patients.

41.3 Enamel-dentin fractures

Left: As part of the primary treatment the previous day, the exposed dentin in teeth 11 and 21 was treated with a calcium-hydroxide cement.

Right: To facilitate manipulation, the tooth fragments were bonded to microbrushes before application of phosphoric acid and dentin adhesive.

41.4 Reattachment—restoration

Left: Following removal of rubber dam, the transition between the freshly attached incisal fragments and the rest of the crown is clearly visible.

Right: The clinical situation 2 years later reveals a satisfactory esthetic result. Both teeth remain vital.

41.5 Composite restoration

Left: Composite restoration was carried out under rubber dam.

Right: Four years following successful treatment, the esthetic clinical situation is unremarkable. Both central incisors continue to react positively to a sensibility test.

Crown Fracture with Pulpal Involvement

Despite traumatic pulp exposure, the prognosis for maintaining tooth vitality in young individuals with crown fractures with pulpal involvement is generally favorable. Treatment of the traumatically exposed pulp depends on the amount of time that has elapsed since the injury. If this occurs within the first 2 hours, direct pulp capping is possible.

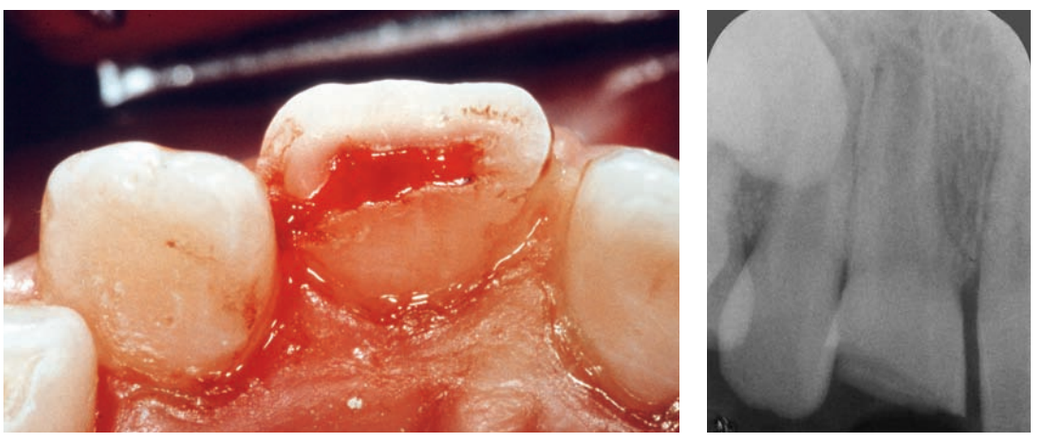
Calcium hydroxide has a proven record as a pulp capping material. When applied to an open, vital pulp, calcium hydroxide elicits the formation of new hard tissue in the area of the perforation. An alternative is mineral trioxide aggregate (MTA), which is preferable from a biologic point of view although tooth discoloration can impair the esthetic result.

Especially when primary treatment is delayed, 1–2 mm of the (potentially infected) pulp should be removed (partial pulpotomy, Cvek, 1978) before capping. The literature reports higher success rates using this method compared to direct pulp capping independent of the size of the pulpal exposure and the status of root growth. Furthermore, it has been demonstrated that pulpal tissue that has been exposed for more than 24 hours to the oral milieu is bacterially infected only in the most coronal region (Cvek, 1982).

41.6 Crown fracture with a wide pulp exposure

A partial pulpotomy is indicated to maintain tooth vitality.

Right: The radiograph reveals incomplete root development of the fractured tooth. The treatment of choice has as its goal continued root development.

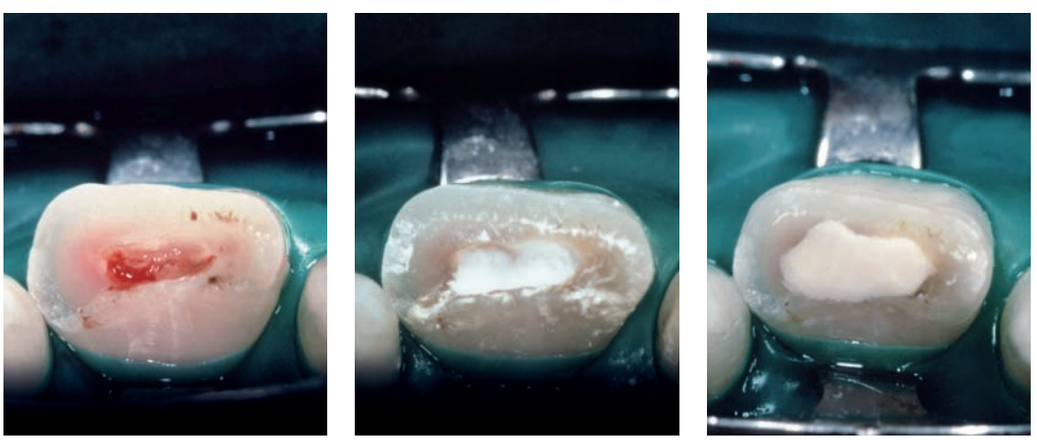


41.7 Partial pulpotomy

Left: Partial amputation of the coronal pulp is carried out using a high-speed diamond bur and cooling with sterile saline solution. Any bleeding should cease within 5 minutes. The lack of continued hemorrhage is evidence that the pulpal tissues are not inflamed, thus confirming the indication for the treatment.

Middle: The artificial wound surface is covered with a calcium-hydroxide preparation.

Right: Covering with a calcium-hydroxide cement.

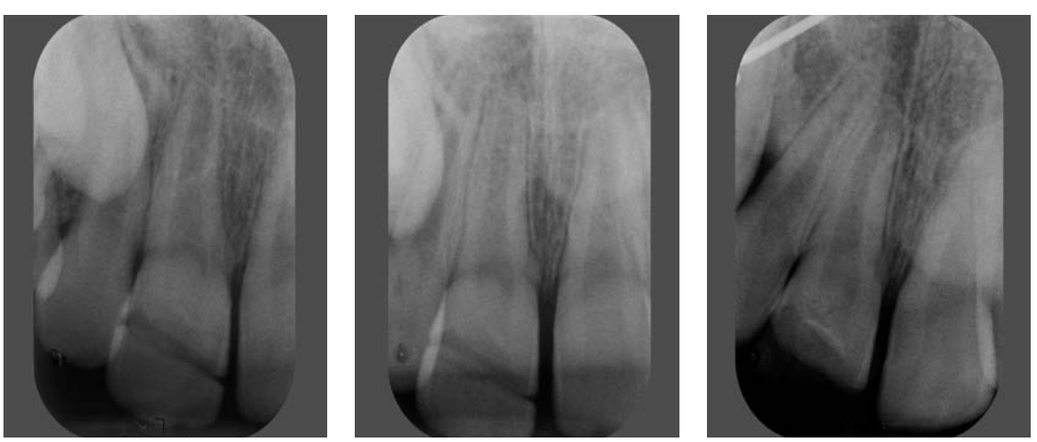


41.8 Radiographic follow-up

Left: At the 6-month recall, the radiograph clearly exhibits the demarcation between the tooth crown and the attached fragments. The fragments were attached using a non-radiopaque composite material.

Middle: The 1-year postoperative radiograph reveals the continuation of root development following partial pulpotomy.

Right: Three years later, a second trauma resulted in the loss of the attached fragments. However, closure of the pulp chamber remains intact.



The goal of partial pulpotomy is the removal of irreversibly damaged pulpal tissue while leaving the healthy tissues that are capable of regeneration. This is especially important in teeth whose root development is not yet complete, so that growth of the root can continue. With this treatment, on the one hand, the time-consuming apexification procedure can be avoided, and on the other hand, the resistance to fracture is increased, bearing in mind that anterior teeth with incomplete root development have a high fracture incidence (Cvek, 1992).

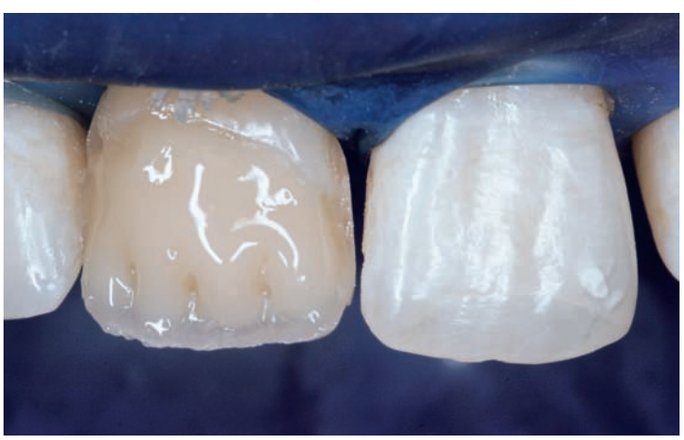
Most critical for the success of all treatments aimed at maintaining vitality is achieving a long-term bacteria-tight seal. In general, if more than 48 hours go by before primary treatment of a traumatically exposed pulp, root canal treatment will be required. In immaturate teeth, use of a an apical plug with MTA prior to further root canal filling has proved its worth as an alternative to conventional apexification using calcium hydroxide.

In terms of restoration, the same options are available as those described for crown fracture without pulpal exposure.

41.9 Composite resin build-up

Clinical view following removal of the old composite build-up for esthetic reasons. Eleven years following trauma, the formerly wide open pulp (see Fig. 41.7) appears to be closed with dentin formation.

Left: Radiograph of the vital tooth. Root development is complete. The resorption at the root tip of the otherwise vital tooth 21 indicates that it was involved in the original trauma.



41.10 Composite build-up

Left: After beveling and conditioning of the tooth structure using phosphoric acid and adhesive, the first procedure is the build-up of the palatal wall with the help of a silicone template.

Right: The artificial dentin build-up using opaque composite provides a good imitation of natural mamelon structure.

41.11 Composite build-up

Left: The labial and incisal regions were built up using a more translucent composite resin. The final procedure is definitive polishing.

Right: The clinical result 1 month following completion of the anterior tooth build-up reveals a good match with adjacent tooth 21.

Crown-Root Fractures

Crown-root fractures of maxillary anterior teeth often exhibit a typical course. Whereas the fracture line in the labial region is located para- or supragingivally, the edges of the fracture on the palatal aspect usually extend deeply into the root itself.

If, following removal of the highly mobile crown fragment, a pulpal exposure is apparent, the treatment is similar to that for a routine crown fracture. The same is true for subsequent restorative attempts as long as the defect is accessible to restorative measures.

In nonvisible areas, the restorative procedure can be restricted to the accessible supragingival regions (e.g., by shortening the fragment before reattachment), with the subgingivally located area remaining untreated. In most cases, however, adequate treatment depends on good access to the trauma site. This can be accomplished by targeted surgical crown lengthening, provided that aesthetics are not compromised. Selective reduction of the alveolar bone makes the defect accessible for restorative treatment. In cases of deep fractures such attempts compromise the supporting alveolar bone for a possible subsequent implant treatment. Therefore extrusion of the remaining root is another alternative, which can be carried out either orthodontically (forced eruption) or surgically.

41.12 Removal of a highly mobile tooth crown following crown-root fracture

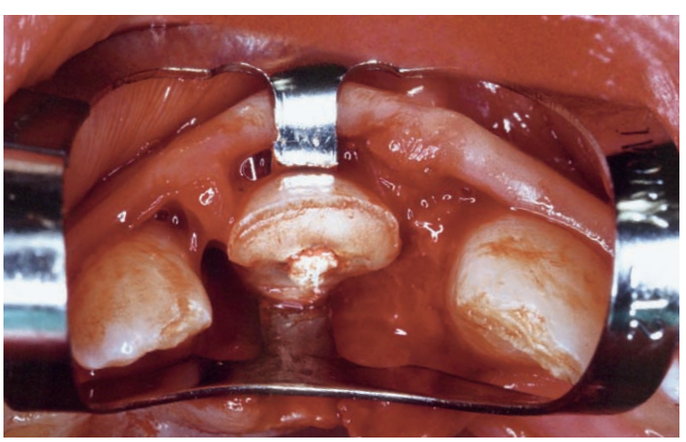
Clinical situation 3 weeks after the trauma; the crown-root fracture was overlooked initially. The crown fragment reveals increased mobility. Because of the prolonged exposure to the oral environment, maintenance of pulp vitality was not possible.

Right: Because of the superimposition of the alveolar bone, only the buccal fracture line is visible on the radiograph.

41.13 Surgical exposure

Following surgical exposure of the fracture surface, the entire defect was able to be visualized, facilitating the seating of a rubber dam clamp.

Right: Crown fragment with a portion of the palatal root.



41.14 Reattachment and further endodontic treatment

Clinical view following adhesive reattachment of the tooth crown. This was followed by conventional root canal treatment.

Right: The working length radiograph reveals the still wide open root apex. Apexification must be carried out before root canal filling and placement of an adhesive glass-fiber post.

Treating teeth with crown-root fractures can present the clinician with a number of challenges, especially periodontal and restorative. The necessary treatment measures are time consuming, and require multiple visits in order to achieve an esthetically and periodontally acceptable result.

There is a lack of data regarding prognosis after treatment of teeth with crown-root fractures. However, success rates are believed to be poorer than for crown fractures (Olsburgh et al., 2002). Despite the often unfavorable relationships between fragment size and the fracture surface, adhesive restorations are usually indicated (reattachment or composite build-up). If endodontic treatment is deemed necessary, the use of an adhesive root canal post will provide additional retention for the restoration.

If the treatment involves a conventional crown, a minimum of 1.5 mm healthy hard tooth tissue must be available to achieve a sufficient ferrule effect (Stankiewicz, 2002); in addition, one must bear in mind the principle of respecting the biologic width (Amiri-Jezeh et al., 2006).

41.15 Crown-root fracture of a maxillary premolar

Clinical examination revealed that the buccal crown fragment was highly mobile.

Left: The removed fragment with the fracture line extending far into the root.

41.16 Surgical extrusion

Left: The root was carefully extracted.

Middle: Following coronal shortening, replantation, and splinting, the 180°-rotated tooth is now accessible for the necessary endodontic treatment.

Right: The radiograph depicts the amount of the surgical extrusion.

41.17 Restoration

The restorative treatment with composite can be regarded as a long-term temporary restoration.

Left: Six weeks following initiation of therapy, the root canals were filled. The periodontal healing process is practically complete. Clinically, the tooth shows physiologic mobility.

Root Fractures

Primary treatment for a root fracture mainly depends on the location of the fracture line in relation to the gingival sulcus. The prospects of preserving both tooth fragments are excellent if there is no connection between the fracture line and the oral cavity.

The aim of repositioning the often dislocated coronal fragment and subsequent splinting is pulpal regeneration and, in an ideal case, the deposition of calcified tissue within the fracture line (Andreasen et al., 2007). The amount of time the splint should be left in situ will depend on the degree of mobility of the coronal fragment; the usual time is 4 weeks (Andreasen, 2004b). The prognosis for teeth with root fractures is favorable, with a success rate of approx. 80% (Andreasen, 2004a). Despite a negative pulpal sensibility test, the often observed obliteration of the pulp canal in the coronal and/or apical root segments provides an indirect clue to surviving vital pulp cells, and is not an indication for endodontic intervention.

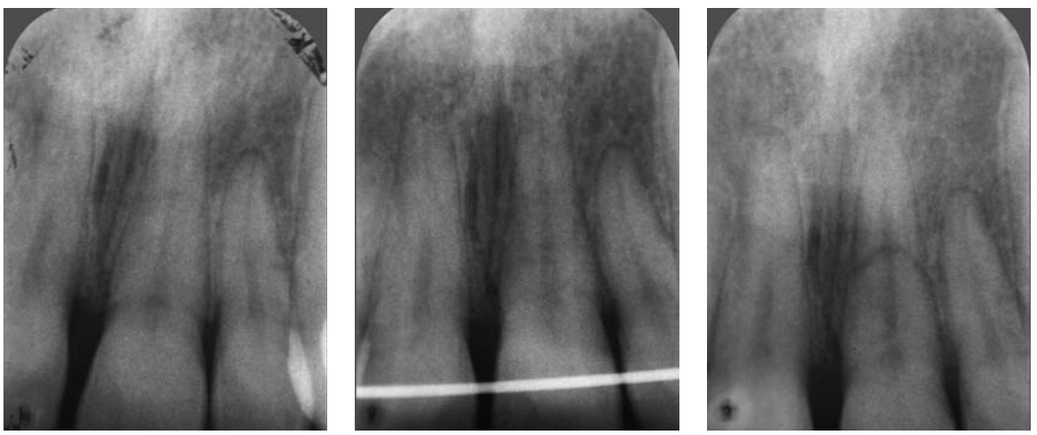
Endodontic treatment limited to the coronal fragment should only be carried out 3 months post trauma at the earliest, if at this point there is no reaction to a pulpal sensibility test and there is reliable clinical and radiographical evidence of endodontically elicited inflammatory reaction. The apical fragment remains vital in almost all cases; hence no treatment is indicated for that part of the tooth.

41.18 Horizontal root fracture

Left: Tooth 21 has a horizontal root fracture in the middle third.

Middle: Radiographic appearance 3 weeks after splinting.

Right: Radiographic appearance 3 months later. The fracture line remains clearly visible because of the ongoing biologic reparative processes.



41.19 Healing following horizontal root fracture

Right: Four years following the trauma, radiographic signs of healing with calcified tissue as well as obliteration in both fragments are visible. This can be interpreted as a clear sign of vitality. There is no need for additional therapy.

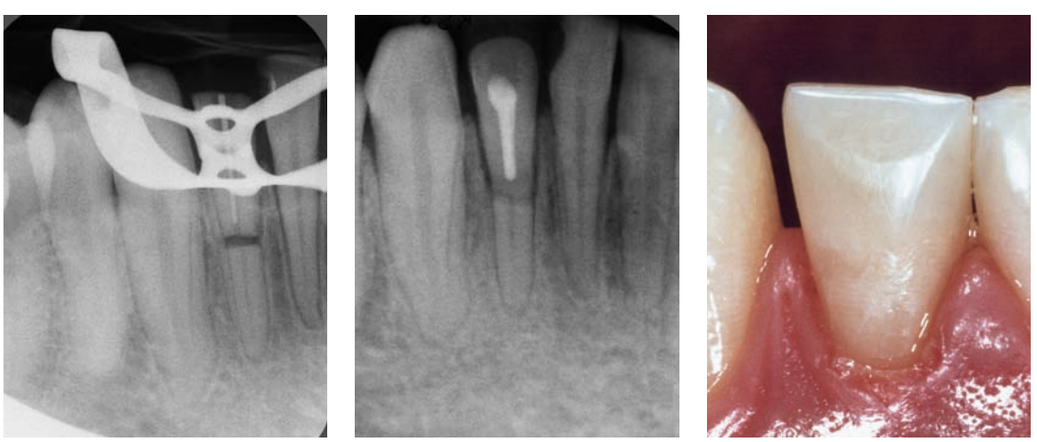
Left: The clinical appearance is unremarkable. The tooth is not mobile, and the maximum periodontal probing depth is 3 mm.

41.20 Pulpal necrosis of the coronal fragment

Left: Length estimation radiograph.

Middle: Radiographic appearance following root canal filling of the coronal fragment. The still-vital apical fragment is radiographically unremarkable and requires no further treatment.

Right: The clinical view is also unremarkable. The slightly increased tooth mobility is evidence of the altered lever relationship with the shortened root; but this should not present long-term problems.

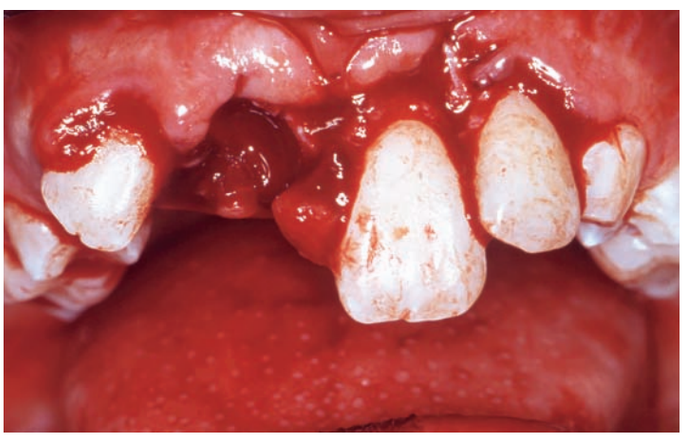


Dislocation Injuries

Tooth dislocation occurs to various degrees, and causes injury not only to the periodontal tissues, but also to the pulp, depending on the degree of displacement of the tooth. Concussion and loosening represent the injury types with the most favorable prognosis.

With tooth mobility, 1–2 weeks of flexible splinting is indicated. In most cases, this leads to complication-free healing of both periodontal and pulpal tissues. In cases of lateral dislocation, the extent of periodontal and osseous injury is greater. Splinting for 2–3 weeks and subsequent functional loading generally lead to regeneration of the periodontal structures.

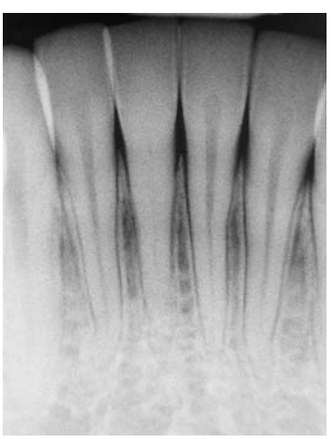
The pulpal tissue prognosis is dependent on the severity of pulp damage at the apex. The highest frequency of pulp necrosis is encountered in cases of intrusions, followed by lateral dislocations and extrusions. In addition, untreated exposed dentin greatly increases the risk for pulp necrosis. A lack of reaction to a standard sensibility test in the first months, or posttraumatic discoloration of the tooth crown, should not be the sole criterion for the decision to carry out root canal treatment (Andreasen et al., 2007).



41.21 Dislocation injury

Complicated case with various dislocation injuries. Tooth 12: lateral dislocation; tooth 11: avulsion; tooth 21: extrusion; tooth 22: increased mobility.

Left: Radiographic view following repositioning of the dislocated incisors and reimplantation of the avulsed tooth, and splinting using a Titanium Trauma Splint (TTS, Medartis AG, Basel, Switzerland). (Courtesy of Dr. Hairass.)



41.22 Concussion of tooth 41

The follow-up radiographs at 6 months (left), 1 year (middle), and 2 years (right) reveal increasing obliteration of the root canal. Despite a considerably delayed reaction to the sensibility test, this provides indirect evidence of the existence of remaining vital pulpal cells; no endodontic treatment is necessary.

41.23 Palatal dislocation

The palatal dislocation of tooth 11 led to occlusal disharmonies. Light bleeding from the sulcus also indicates injury to the tooth-supporting apparatus. The adjacent teeth have crown fractures.

Left: The occlusal view makes clear the extent of the dislocation of tooth 11. The required primary treatment includes repositioning of the tooth and splinting, as well as treatment of the exposed dentin.

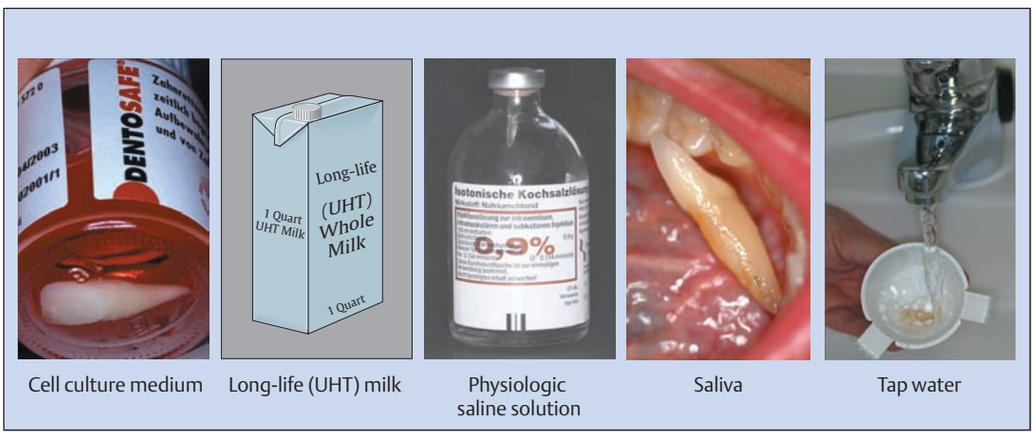
Avulsion

Tooth avulsion implies complete severing of the periodontal fiber apparatus and damage to small areas of the root cementum. In addition, there is injury to the supporting alveolar bone structure, rupture of the neurovascular supply to the pulp, and bacterial colonization of the root surface and the endodontium.

A high chance of survival of cementoblasts on the root surface is an important prerequisite for preservation of the avulsed tooth. If the tooth is replanted immediately at the site of the injury, the periodontal ligament left attached to the root surface does not dry out. Periodontal healing can be expected and the prognosis is good. After excessive drying, however, the periodontal ligament cells lose their viability (Trope, 2002). For this reason the use of an appropriate storage medium is mandatory (Lekic et al., 1998). If a specialized cell culture medium is not available, cold milk or physiological saline is an option for a short period.

41.24 Transport media for avulsed teeth, in the order of their indication

A commercial tissue culture medium (e.g., Dentosafe-Box) is the ideal medium to preserve periodontal ligament cells up to 24 hours. Although cold, long-life milk can be used for a few hours; saline solution is not as effective because of the absence of nutritional substances. Because of its hypotonic characteristics and high bacterial content, saliva is not particularly indicated, nor is tap water.



Cell culture medium | Long-life (UHT) milk | Physiologic saline solution | Saliva | Tap water

41.25 Therapeutic recommendations for avulsed teeth depend on the storage medium and the time outside the mouth

This therapeutic table is based upon the current recommendations of the International Association of Dental Traumatology (IADT). The replantation of an avulsed tooth rinsed with physiologic saline solution should be carried out without pressure into a clot-free alveolus to avoid any further damage to the periodontal structures. In addition, the systemic administration of doxycycline is recommended as an adjuvant therapy.

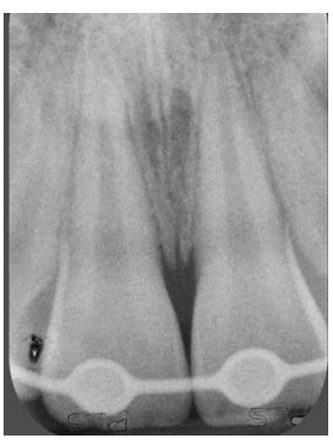
Type of storage and extra-alveolar time	Teeth with completed root growth	Teeth with wide open apex
Dry or moist storage <15 minutes or storage in a cell culture medium for up to 24 hours	Replantation, splinting for 7–10 days Root canal instrumentation 7–10 days later Medicated dressing for at least 1 week	5 minutes treatment in doxycycline solution (1 mg in 20 mL 0.9% NaCl solution) Replantation, splinting for 7–10 days No primary root canal treatment
Dry storage 15–60 minutes or short-term storage in milk or physiologic saline solution	30 minutes soak in a cell culture medium desirable Replantation, splinting for 7–10 days Root canal instrumentation after 7–10 days Medicated dressing for at least 1 week	Apexification with calcium hydroxide or MTA as apical closure before root canal filling
Dry storage >60 minutes	Complete removal of root cementum 20 minutes storage in fluoride solution Replantation, splinting for 4 weeks Root canal instrumentation after 7–10 days Alternative: Extraoral root canal treatment	Usually replantation is not recommended

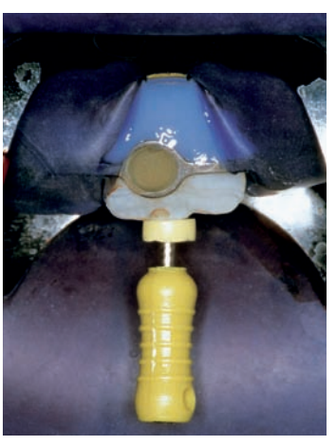
After replantation, the avulsed tooth is stabilized with a flexible splint for 1–2 weeks to encourage periodontal healing. In mature teeth, root canal treatment should be initiated before removal of the splint to prevent infection-related root resorption. In teeth with incomplete root formation and wide open apices (with a short extra-alveolar time) pulp revascularization and, subsequently, continued root development may occur (Andreasen, 1995). Primary endodontic treatment will not be required in such cases. Well-coordinated clinical and radiographic follow-up will help in the early identification and treatment of any possible complications. Extensive necrosis of the periodontal ligament following prolonged or nonphysiologic intraoral storage of the avulsed tooth will lead to ankylosis. The root will be gradually replaced by bone (osseous replacement). If replantation is to be attempted in such cases, all of the necrotic root cementum must be completely removed. The goal is to slow down the unavoidable resorptive process.

41.26 Avulsion

A 10-year-old patient with avulsion of tooth 21. Before initiation of therapy, the avulsed tooth was left to dry for 10 minutes and then immersed in cold milk for 45 minutes. To improve the chances for periodontal healing, a 30-minute immersion in a cell culture medium is recommended.

Left: Determination of the tooth length will simplify subsequent endodontic treatment.





41.27 Radiograph and endodontic treatment

Left: The periapical radiograph shows that there are no residual fragments within the alveolus. It also shows that there is no fracture of the adjacent teeth.

Middle: The radiograph shows the proper positioning of the replanted and splinted tooth.

Right: Root canal treatment with intracanal medication (calcium hydroxide) before removing the splint, 8 days after the trauma.

41.28 Root canal filling and clinical appearance

Left: The follow-up radiograph after endodontic treatment with gutta-percha and sealer, using the lateral compaction technique, shows a bacteria-tight root canal filling.

Right: Following completion of treatment, the clinical appearance is unremarkable. Because of the suboptimal storage conditions of the avulsed tooth following trauma, external root resorption cannot be excluded. Annual check-ups are necessary.

Consequences of Dislocation Injuries

One possible consequence of dislocation injuries is the occurrence of external root resorption. This mainly depends on the extent of damage to the cementum layer, and determines for the most part the prognosis of the traumatized tooth. Extensive necrosis of the cementum, especially that associated with serious dislocation trauma such as intrusion and avulsion, inevitably leads to replacement resorption (osseous replacement). This process is also enhanced by the use of rigid splints and/or prolonged splinting periods because of the lack of functional stimulation of the healing periodontal tissues.

The tooth root is gradually resorbed by dentinoclasts and the resorbed root segments are replaced by bone. In young patients, the affected tooth will become infraoccluded due to ankylosis and local lack of development of the alveolar bone. On percussing the tooth, the clinician will hear a typical metallic sound. Radiographically, the root has a "moth-eaten" appearance with absence of the periodontal ligament space.

In addition, if infection of the pulp that has been caused by the trauma is not treated in a timely manner, infection-related root resorption will occur. This process is supported by the microorganisms and their toxins, which reach the damaged periodontal tissues from the root canal via the dentinal tubules. This can lead, in the most severe cases, to virtual destruction of the affected root within only a few months.

41.29 Ankylosis

Left: Six years following replantation of a maxillary anterior tooth with incomplete root development, the tooth root appears to be almost completely replaced by bone as a result of the root resorption. A fracture of the clinical crown is likely.

Right: The clinical view shows the infraoccluded ankylosed tooth 21.

41.30 Infection-related root resorption

Left: Radiographic view following replantation and splinting of two avulsed anterior teeth following extra-alveolar storage in a moist towel for over 60 minutes.

Right: Radiographic view 3 months after the primary treatment; during this period of time, unfortunately, no additional treatment was provided. The fact that no endodontic treatment was carried out led to an infection-related root resorption and a massive loss of tooth hard substance and alveolar bone (courtesy of Dr. Meller).

There is controversy (Andreasen, 2005) as to how far the occurrence and progression of external root resorption can be influenced by various treatment modalities such as intracanal dressings (Bryson, 2002) or the application of corticoid solutions and/or Emdogain to avulsed teeth (Pohl, 2005a, b, c). Clinical studies have reported favorable results (Chappuis and Von Arx, 2005). Because of its antiresorptive characteristics, the systemic administration of doxycycline can be recommended following severe dislocation injuries. In children under the age of 8, however, there is danger of tetracycline staining of the not yet completely mineralized crowns of second and third molars. Usually, this is not likely to happen because of the short-term administration of the antibiotic.

The most important treatment measure in terms of preventing infection-related root resorption is timely and effective endodontic treatment, if it is indicated.

42 Tooth Resorption

Resorption can be a physiologic or a pathologic process, and results in loss of dentin, cementum, or bone. Resorption may occur subsequent to traumatic dental injuries, orthodontic treatment, or chronic infections of the pulp or periodontal tissues.

Under normal circumstances, the mineralized tissues of permanent teeth are resistant to resorption. They are protected by a layer of predentin and precementum, on which clastic cells cannot gain foothold. If, however, this protective layer is damaged or altered by an injury in conjunction with an inflammation of the pulp or periodontal tissues, then multinucleated clastic cells will induce resorption.

Tooth resorption is classified on the basis of the site, nature, and pattern of the process (Ne et al., 1999). A distinction is generally made between internal and external resorption. External resorption can be further subdivided into external surface resorption, invasive cervical resorption, inflammatory root resorption, ankylosis, and replacement resorption.

Internal resorption is the only type of resorption that starts within the root canal, and it frequently results from chronic inflammation of the pulp. Vital pulp tissue is a prerequisite for active internal resorption. In the initial stage, the coronal portion of the pulp is totally or partially necrotic, whereas the apical pulp, which includes the internal resorption defect, can remain vital and inflamed. Therefore, pulp sensibility tests can remain positive (Trope, 2002).

Internal resorption is generally asymptomatic and is usually identified by chance on routine radiographs.

External surface resorption is a transient phenomenon in which the root surface undergoes spontaneous destruction and repair. It is found in all teeth, in varying degrees, and is probably a normal physiologic response. Hence, it requires no treatment (Ne et al., 1999).

Invasive cervical resorption is an insidious and often aggressively destructive form of external tooth resorption. It is a relatively uncommon condition that may occur in any tooth of the permanent dentition. It is characterized by invasion of the cervical region of the root by fibrovascular tissue, derived from the periodontal ligament. This resorptive process leads to progressive loss of tooth structure and may eventually invade the pulp space. However, the pulp survives until late in the resorptive process, because it is protected by the predentin and odontoblasts (Heithersay, 1999a). The etiology of this condition is poorly understood, but intracoronal bleaching, trauma, orthodontics, dentoalveolar surgery, and periodontal treatment have been cited as potential predisposing factors (Heithersay, 1999b).

In *inflammatory root resorption*, the necrotic, infected pulp provides the stimulus for periodontal inflammation. The most common cause of external inflammatory root resorption is trauma. If the cementum has been damaged, leaving the dentinal tubules exposed, this creates an open communication between the internal and external surfaces of the root. Bacteria and their by-products, and tissue breakdown products from within the pulp space, diffuse through the dentinal tubules and stimulate an inflammatory response over large areas of the periodontal ligament, leading to aggressive and progressive resorption of the root (Andreasen, 1981).

Ankylosis and *replacement resorption* are primarily associated with a history of luxation injuries, in particular in avulsed teeth with an extended extra-oral dry time. If osteoblasts are able to cover the root surface after necrosis of the periodontal ligament, direct contact with bone and root will occur over some areas of the root surface. The term for this condition is *ankylosis*. Reversal of ankylosis is possible if less than 20% of the root surface is involved. If not, the root will gradually be replaced by bone (Tronstad, 1988).

Diagnosis of Resorption

It can be difficult to distinguish between invasive cervical resorption and internal root resorption. This may result in an inaccurate diagnosis and subsequently incorrect treatment.

Radiographically, internal resorption appears as a circumscribed, oval-shaped enlargement of the root canal space. The outline of the root canal is often distorted, and the resorption appears to be contiguous with the root canal. Regardless of the projection angle of the radiograph, internal resorption remains centered in the root.

Invasive cervical resorption moves away from the canal if the angle of projection of the radiograph is changed. In addition, the root canal outline appears normal and can usually be identified through the defect, in contrast to internal resorption.

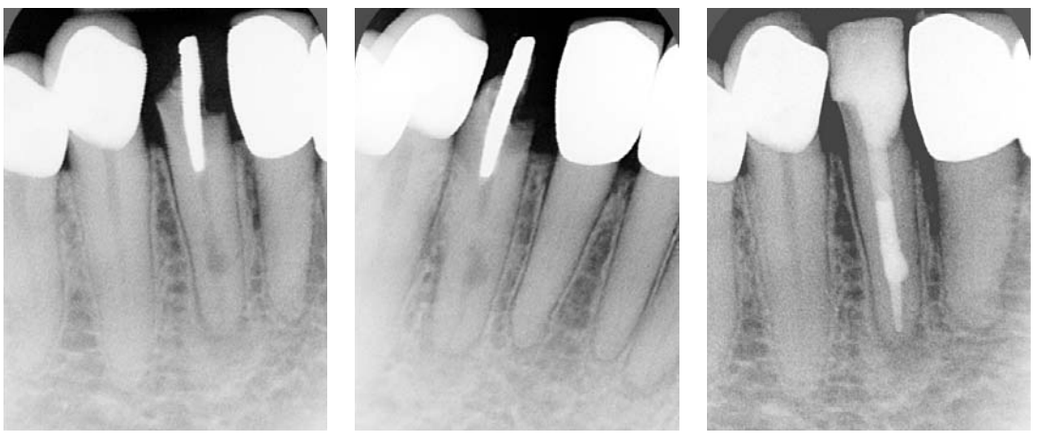
Clinically, the presence of a pink spot in the coronal dentin can be a feature of both internal and invasive cervical resorption. This phenomenon occurs due to the presence of granulation tissue just under the enamel. In both conditions, a pulpal sensibility test is likely to be positive, because the pulp remains (partially) vital.

42.1 Internal root resorption

Left: Perpendicular periapical radiograph showing an internal resorption defect on tooth 42 with an apical radiolucency. Note the oval, circumscribed radiolucent enlargement of the root canal.

Middle: A radiograph taken from a different horizontal angle shows that the defect stays centered in the root.

Right: Postoperative radiograph confirms that the entire canal including the internal resoption defect has been filled, in this case with MTA. Failure to achieve this would indicate the presence of external resorption defect.

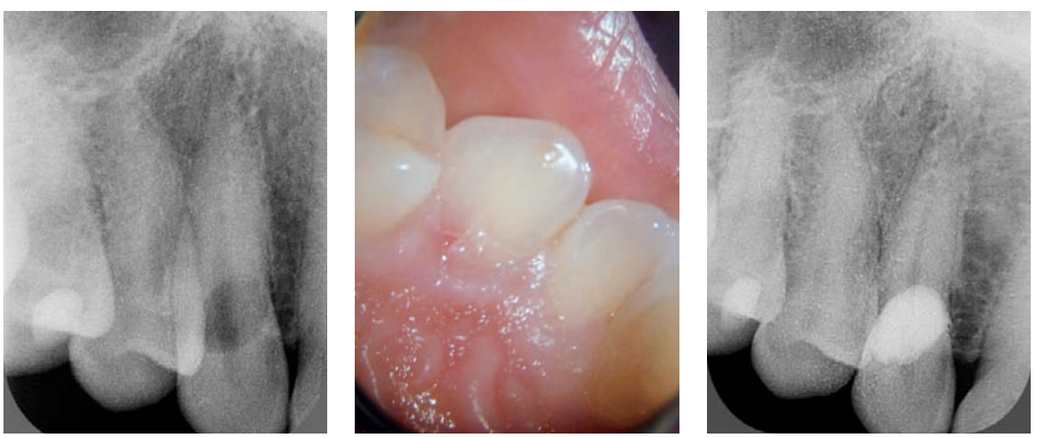


42.2 Invasive cervical resorption

Left: Radiograph showing invasive cervical resorption on tooth 13. The outline of the canal is clearly visible through the resorption defect. The tooth tested vital.

Middle: A pink spot on the palatal surface indicates the presence of granulation tissue undermining the enamel.

Right: The 1.5-year follow-up radiograph showing the resorption defect restored with a composite filling. Pulpal sensibility tests were positive, and there were no signs of periapical pathosis.

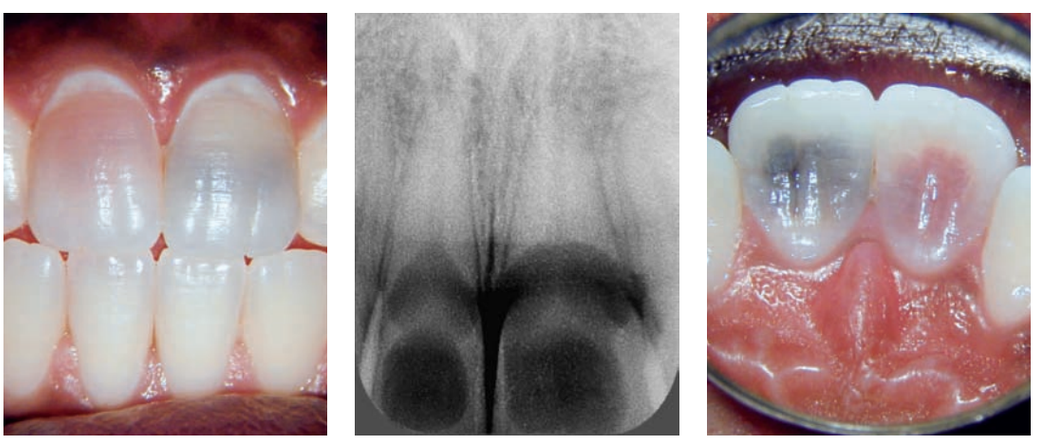


42.3 Severe internal resorption on two maxillary central incisors

Left: Teeth 11 and 21 exhibiting reddish and black discoloration, due to internal resorption, respectively.

Middle: Extensive radiolucencies in the coronal and cervical segments of the root canals of 11 and 21.

Right: Palatal aspect of affected central incisors. The teeth have been significantly weakened as a result of the resorption. Soon after the initial examination, the crown of tooth 11 broke off.



External inflammatory root resorption is always accompanied by resorption of bone, so radiolucencies in the root and the adjacent bone can be identified on the radiograph. Because external inflammatory root resorption is associated with an infected pulp, there will be a negative response to a pulpal sensibility test.

Pressure has also been identified as a possible etiological factor for external inflammatory root resorption, as evidenced by resorption that may occur in conjunction with orthodontic tooth movement, tooth eruption, tumors, cysts, and impacted teeth. In such cases, the resorption tends to cease as soon as the source of pressure is removed (Ne et al., 1999).

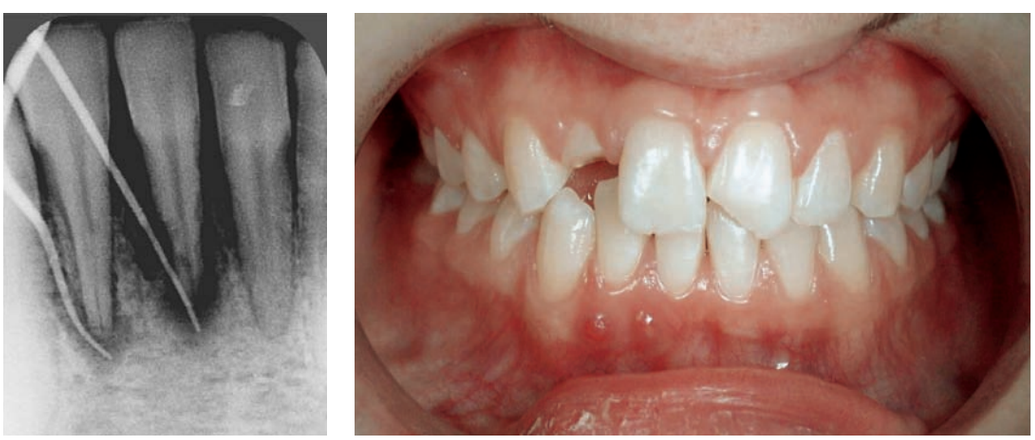
Clinically, ankylosis and replacement resorption are recognized by immobility of the affected teeth. Depending on the age at which the ankylosis has occurred, the tooth may be in infraocclusion. The percussion test is an important diagnostic tool, because a typical metallic percussion sound is produced when these teeth are tapped, which is very different from sound produced on tapping the healthy adjacent teeth. Radiographic features include absence of a periodontal ligament space. Replacement resorption may give the tooth a "moth-eaten" radiographic appearance, with irregular borders.

42.4 External inflammatory root resorption

Left: Severe external inflammatory root resorption in 11 and 21 after avulsion of 11 and intrusion of 21. Timely root canal treatment could have prevented this.

Middle: External inflammatory root resorption in conjunction with orthodontic treatment, which ceased following its conclusion.

Right: External inflammatory root resorption in tooth 17, probably due to longstanding pressure from a third molar, which had been extracted a few years earlier.



42.5 External inflammatory root resorption after dental trauma

Left: Sixteen-year-old girl who sustained trauma with a hockey stick 3 months previously. Teeth 41 and 42 were avulsed and reimplanted within 10 minutes. Unfortunately, root canal treatment was postponed, which resulted in external inflammatory root resorption in both teeth. Two sinus tracts can be identified.

Right: Radiograph showing tracing of the fistulous tracts with gutta-percha cones. Multiple radiolucencies in the roots and bone are visible.

42.6 Replacement resorption

Left: A 7-year-old patient sustained trauma with avulsion of tooth 11. It was replanted after 1 hour extra-oral dry time.

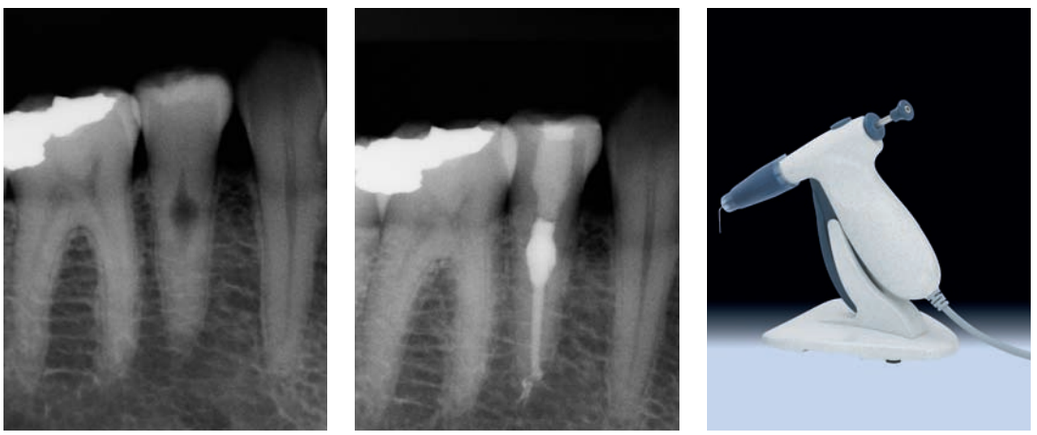
Middle: Several months later, signs of replacement resorption can be identified. An apexification procedure using calcium hydroxide was initiated; the tooth was filled with an apical plug of MTA and a build-up of composite resin.

Right: Six-month follow-up radiograph showing infraposition of tooth 11, due to replacement resorption.

Treatment of Internal and Inflammatory Resorption

The recommended treatment for internal resorption is conventional endodontic therapy to stop the process at an early stage and prevent the onset of a perforation. If a perforation has already occurred, the treatment is not very different from that of repairing an iatrogenic perforation. In addition to closing the perforation, measures must be taken to strengthen the tooth and to prevent it from fracturing. Adhesive restorations with composite are recommended to increase resistance to fracture.

Inflammatory root resorption resulting from pulpal necrosis or periodontal injury should be treated by root canal treatment. By disinfecting the pulp canal space, the inflammatory stimulus will be restrained, and the external inflammatory resorption can be arrested. In most cases, favorable healing with laying down of cementum will occur, but if a large area of the root is affected, osseous replacement may take place. Trope (1995) has recommended the use of a long-term dressing of densely packed calcium hydroxide in cases in which inflammatory root resorption has been established. Calcium hydroxide can create an alkaline pH in the surrounding dentinal tubules, and can kill bacteria and neutralize endotoxin, a potent inflammatory stimulator.



42.7 Treatment of internal resorption

Left: Patient referred endodontic treatment of tooth 45.

Middle: Obturation of such internal defects is best performed with a warm filling technique. The Obtura II gun (Obtura/Sportan, MI, USA) was shown to provide the best results, and lateral compaction the worst, when comparing various methods of obturating experimental resorptive defects (Goldberg et al., 2000).

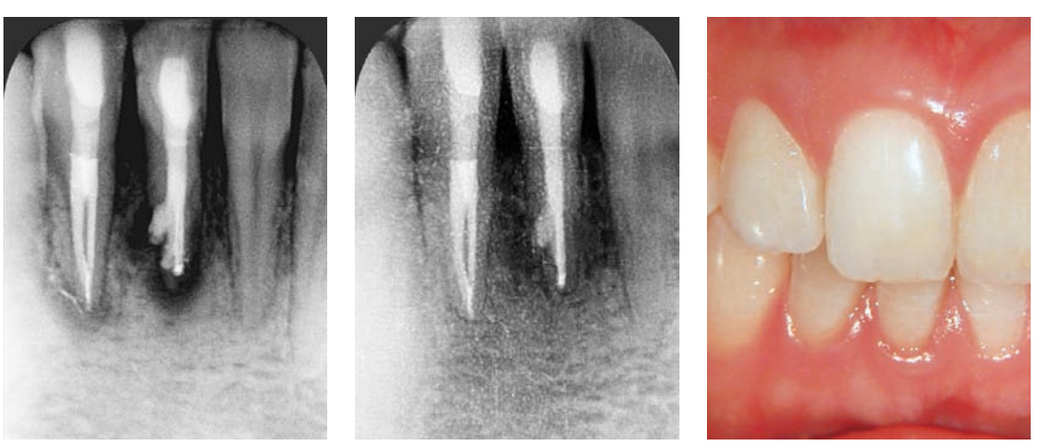
Right: Obtura II gun, a delivery system for thermoplasticized gutta-percha or Resilon (Pentron Clinical Technologies, Wallingford, CT, USA).

42.8 Treatment of inflammatory root resorption

Left: This is the same patient as shown in Figure 42.5. Teeth 41 and 42 were avulsed and reimplanted within 10 minutes. The teeth were rigidly splinted for 6 weeks in contravention of the guidelines, which recommend 1–2 weeks using a flexible splint.

Middle: Timely root canal treatment could have prevented the external inflammatory root resorption of teeth 41 and 42.

Right: Three months after the trauma, root canal treatment was initiated.



42.9 Perforation repair and follow-up

Left: As a result of the inflammatory resorption, tooth 41 appeared to have two perforations. After an intracanal dressing of calcium hydroxide, MTA was used for perforation repair, and the remaining segments of the canals were filled with gutta-percha and sealer.

Middle: 3.5-year follow-up radiograph showing resolution of the apical and lateral radiolucencies of teeth 42 and 41.

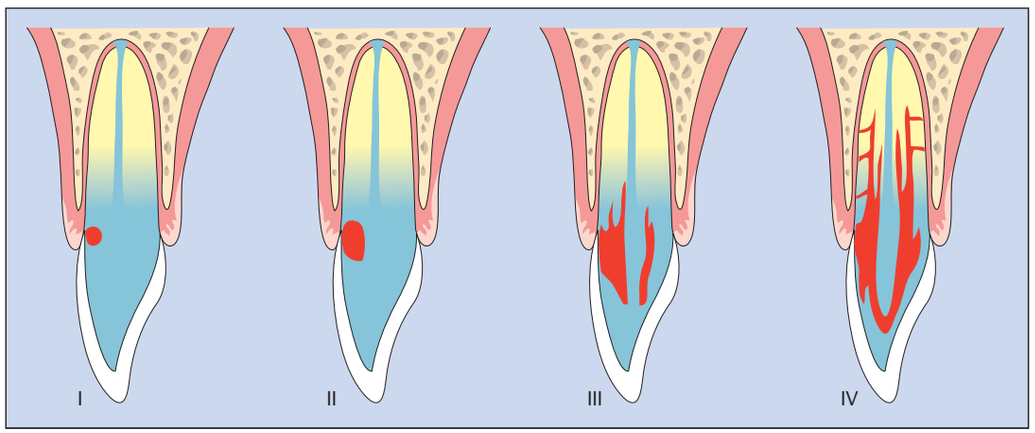
Right: Clinical view after 3.5 years, revealing a healthy periodontium.

Treatment of Invasive Cervical Resorption

The aim of the treatment of invasive cervical resorption is removal or inactivation of all active resorptive tissue and the restoration of the defect with a good sealing fill material. This procedure can be very challenging, due to the infiltrative nature of the resorption in later stages. More advanced resorption lesions are characterized by a series of small channels, often interconnecting with the periodontal ligament apical to the primary lesion.

Depending on the extent of the resorptive process, such cases are divided into four classes in order of severity (Heithersay, 1999b). With more advanced lesions, in which complete removal would cause severe damage to the tooth, an attempt can be made to cut off the blood supply to the resorptive tissue.

Heithersay (1999c) has shown good results using topical application of a 90% aqueous solution of trichloroacetic acid (TCA) in the treatment of class I and II cases. This agent causes coagulation necrosis of the resorptive tissue, without negatively affecting the potential for repair of the adjacent tissues. It has the potential to inactivate tissues in the channels that would normally remain inaccessible to mechanical debridement.



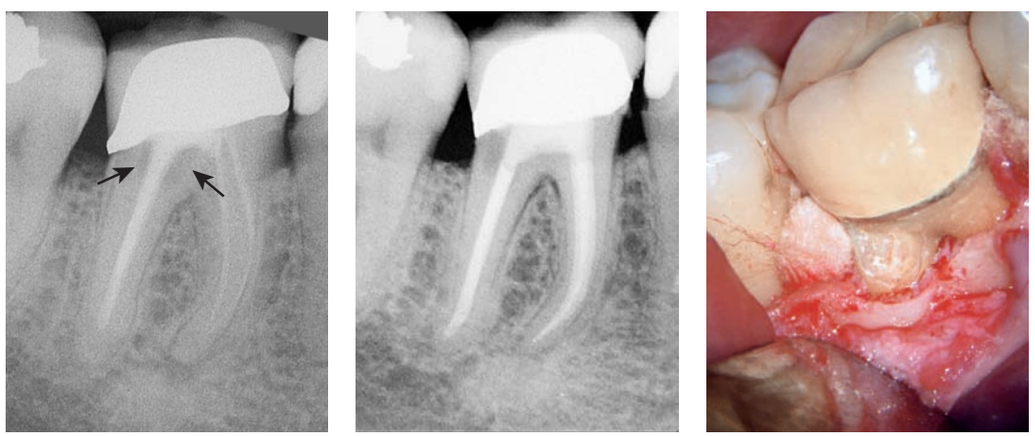
42.10 Classification according to Heithersay

Class I: A small resorptive lesion near the cervical area with shallow penetration into dentin.

Class II: A well-defined resorptive lesion that has penetrated close to the coronal pulp chamber, but exhibits little or no extension into the radicular dentin.

Class III: A deeper invasion of dentin by resorbing tissue, extending into the coronal third of the root.

Class IV: A large invasive resorptive process that has extended beyond the coronal third of the root.

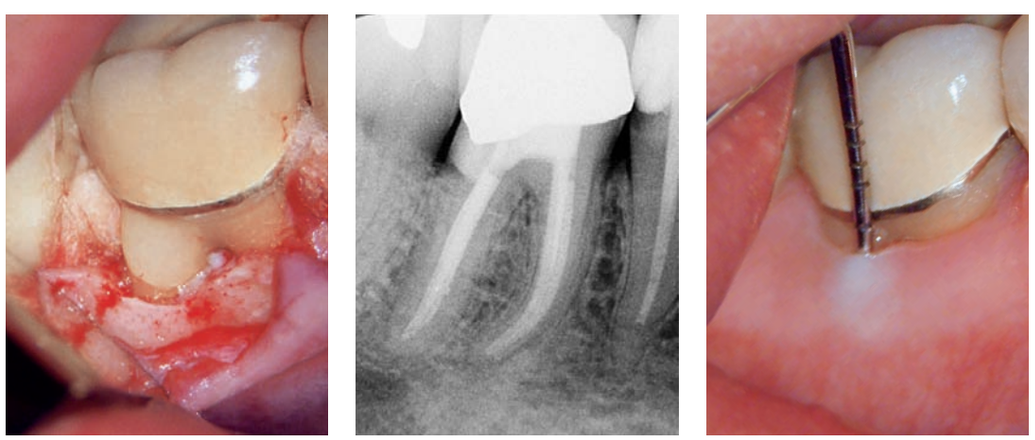


42.11 Treatment of invasive cervical resorption class II

Left: Patient was referred for retreatment of tooth 46. The radiograph reveals a cervical resorptive defect on the distal aspect of the tooth.

Middle: Retreatment has been completed; there was no communication between the root canal system and the resorptive defect.

Right: A flap was elevated to gain access to the resorptive lesion, and a topical application of TCA was used to inactivate the granulomatous tissue.



42.12 Restoration of the defect with composite and follow-up

Left and middle: After inactivating the granulomatous tissue, another challenge is presented—restoration of the defect. In this case, a composite restoration was placed, but due to its location below the attachment level, may promote build-up of a periodontal pocket. At best, a long epithelial attachment may ensue.

Right: Three months after surgery, buccal gingival recession of 2 mm is evident. Probing depth is 3 mm but there is no bleeding on probing.

The resorptive tissue can be accessed either by an external approach, an internal approach, or by a combination of the two. When using an external approach, a periodontal pocket often persists after restoring the defect. This problem may be overcome by orthodontic extrusion of the tooth before treatment, which will improve access to the defect and provide a supragingival margin for the restoration.

If the resorption is extensive, elective endodontic treatment may be required to allow visualization of the area and to gain access to the more deeply infiltrating tissue surrounding the root canal.

The treatment of class IV lesions has a high failure rate (Heithersay, 1999c), raising the question as to whether an attempt should be made to treat such cases. Extraction and replacement with an implant or bridge has been recommended (Trope, 2002). An alternative would be to leave the resorption untreated and inform the patient that tooth loss may occur in the future.

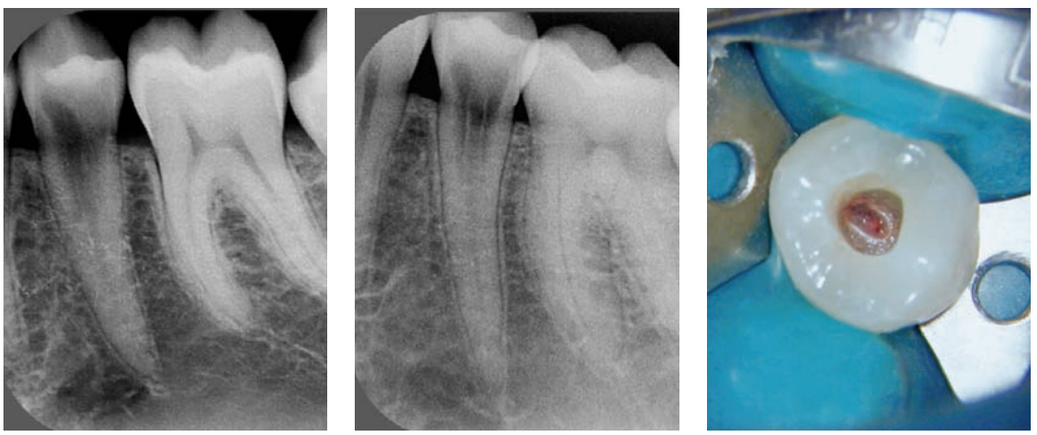
The speed of spread of invasive cervical resorption has not been investigated, but clinical observation suggests that, in the absence of infection, progress is slow.

42.13 Treatment of a class III resorptive lesion using an internal approach

Left: Invasive cervical resorption on tooth 35. Pulpal sensibility testing was positive and there were no significant probing depths.

Middle: Eccentric projection radiograph shows an undistorted outline of the root canal, which is visible through the defect. Elective endodontic treatment was recommended to enable access to the resorptive process.

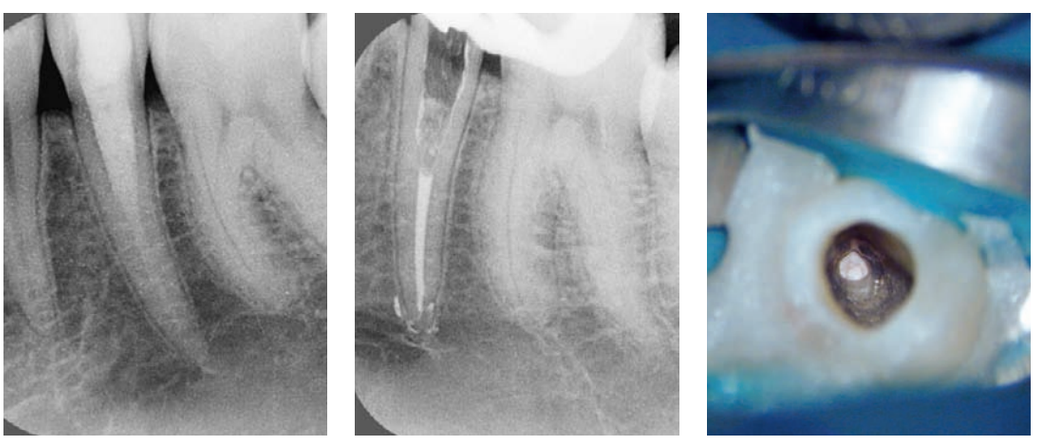
Right: On opening the tooth, a white line surrounding the root canal is visible, representing a layer of predentin.



42.14 Topical application of TCA

Left: After cleaning and shaping the root canal and applying TCA to inactivate the granulomatous tissue, an intracanal dressing of calcium hydroxide, which also has tissue-dissolving properties, was applied.

Middle and right: The root canal has been filled (second visit). The coronal third of the root has been affected by the resorptive process. The goal of TCA use is to cut off the blood supply to the resorptive tissue in the channels.



42.15 Definitive composite restoration and follow-up

Left: A composite build-up has been made, to obtain a coronal seal and to reinforce the tooth that has been weakened by the loss of dentin resulting from the resorption.

Middle and right: At the 1-year follow-up, the radiograph shows no signs of pathosis or recurrence of the resorption. Probing depths are within normal limits, and the patient is free of symptoms.

Treatment and Prevention of Replacement Resorption

Currently, there is no reliable procedure that can cause arrest of replacement resorption after its initiation. The resorbing cells in ankylosis and replacement resorption are osteoclasts. Osteoclasts are normally involved in bone remodeling and are unable to distinguish between cementum, dentin, and bone. Therefore, replacement resorption and ankylosis should be considered as physiologic, rather than pathologic processes (Tronstad, 1988).

Since replacement resorption is primarily associated with luxation injuries, it is of paramount importance to prevent these injuries from occurring. The use of a mouth-guard in contact sports has proven to be effective. Furthermore, after an injury has taken place, additional damage should be minimized. In the case of an avulsion, extra-oral dry time should be minimized by immediate reimplanting of the tooth or storing it in an appropriate medium (e.g., milk).

Another strategy is to make the cementum more resistant to resorption after an extended extra-oral dry time. Emdogain (Staumann, Basel, Switzerland) has been recommended for promoting development of new periodontal ligament from the socket. However, treatment results have varied (Filippi et al., 2002; Schjott et al., 2005), and therefore its use is still controversial. Emdogain is not yet available worldwide.

42.16 Avulsion of teeth 11 and 21

This patient was involved in a bicycle accident, during which she sustained severe dental trauma. Teeth 11 and 21 were avulsed and fractured, tooth 22 was luxated, and the alveolar process was fractured. Teeth 11 and 21 were reimplanted by an oral surgeon after 30 and 45 minutes extra-oral dry time, respectively, and a rigid splint was placed. At the first visit, 1 week after the accident, the splint was adjusted for patient comfort and to enable the patient to carry out proper oral hygiene.

42.17 Root canal treatment and removal of the splint

Left: One week after the accident, endodontic treatment was carried out on teeth 11 and 21.

Right: The splint was removed after 4 weeks. Before the accident occurred, the maxillary dental arch was uniform and regular. After the reimplantation, teeth 11, 21, and 22 appeared to be malpositioned. The patient declined orthodontic treatment, and chose to have the malpositions masked with composite veneers.

42.18 Follow-up

Left: Clinical picture after completion of the restorative treatment. Teeth 12, 11, 21, and 22 were provided with composite veneers.

Right: Seven-year follow-up radiograph showing replacement resorption on teeth 11 and 21. Note the absence of the periodontal ligament space on the distal aspect of 11 and 21. Clinically, a high metallic percussion sound confirmed the diagnosis. The speed at which replacement resorption takes place varies, and may take years to decades. Tooth 21 also reveals a severe invasive cervical resorption.

43 Perforations

A root perforation is a mechanical or pathologic communication formed between the supporting periodontal apparatus of the tooth and the root canal system (AAE glossary, 2003). Perforations occur as a complication of endodontic treatment and restorative procedures such as post preparation; the reported rate ranges from 1% to 3% (Kerekes and Trondstad, 1979; Eleftheriadis and Lambrianidis, 2005; Jamani and Fayyad, 2005). In addition to iatrogenic perforations, pathologic processes such as tooth resorption or caries may also result in root perforation.

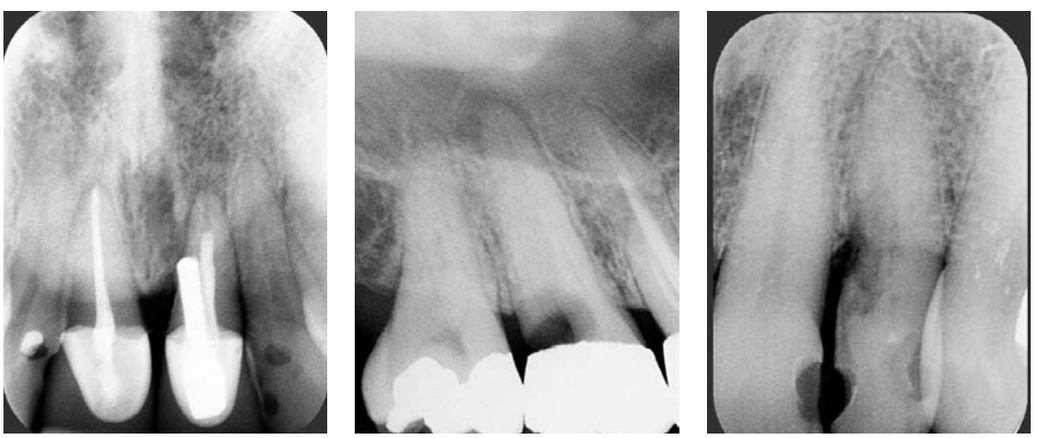
Kvinnsland et al. (1989) evaluated the etiology and location of 55 root perforations seen in a dental school in Norway. Almost 50% of the perforations were due to endodontic treatment and slightly more than 50% were due to prosthodontic treatment. The buccal and mesial root surfaces, as well as the midroot areas, were most often perforated.

According to Fuss and Trope (1996), the important factors in determining the success of a perforation repair are the time interval between the occurrence of a perforation and its repair, the size of the perforation, and its location. The authors presented a classification of root perforations based on the above factors.

The location of the perforation in relation to the level of the epithelial attachment and crestal bone is probably the most important factor in terms of prognosis. The closer the perforation is to this critical zone, the poorer the prognosis, due to susceptibility of the site of perforation to contamination from microorganisms from the oral cavity. Moreover, if the perforation is not closed immediately, apical migration of the epithelial attachment may occur, resulting in a periodontal defect. Fuss and Trope (1996) concluded that successful treatment depends mainly on immediate sealing of the perforation and prevention of infection.

Classification of Root Perforations

Good prognosis	*Poor prognosis*
– Fresh	– Old
– Small	– Large
– Apical-coronal	– High alveolar ridge



43.1 Perforations caused by a procedural error, caries, or a resorption process

Left: Radiograph showing a crestal perforation, due to a misaligned post placement.

Middle: Radiograph showing deep caries resulting in perforation.

Right: Radiograph showing cervical invasive resorption resulting in perforation.

Diagnosis of Perforation

As the time interval between the occurrence of the perforation and its repair is an important prognostic factor for treatment outcome, early determination of the occurrence of a perforation is of paramount importance. A diagnosis is established based on clinical and radiographic findings. Radiographs from different angles, including bitewing radiographs, are indispensable for an accurate diagnosis. In addition, the presence of a sinus tract or the appearance of localized problems such as pocket formation or furcation involvement may indicate the existence of perforation (Aldahainy, 1994).

During treatment perforations can be identified by direct observation through the microscope, direct observation of bleeding at an unanticipated location, indirect bleeding assessment using a paper point, and the use of an apex locator. Moreover, reports of sudden and unprovoked pain may indicate that the file is penetrating the surrounding bone.

Management of perforations will depend on a number of factors, including the size and location of the perforation and access to the perforation site. Subgingival perforations can usually be repaired with materials such as amalgam, composite or cast metal restorations, by extending the cervical margin to include the defect.

43.2 Subgingival perforation

Left: Radiograph showing a maxillary first molar with a large restoration and an insufficient root canal filling in the mesial root. Because a crown has been planned on tooth 26, retreatment is appropriate. Localized gingivitis is present between teeth 25 and 26, and a perforation is suspected on the mesial aspect of tooth 26, because of the close proximity of the restoration to the interdental papilla.

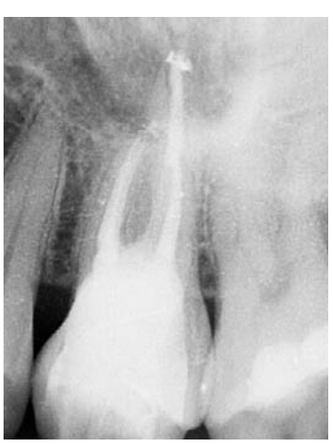
Right: After removing the composite restoration, a subgingival perforation became visible.

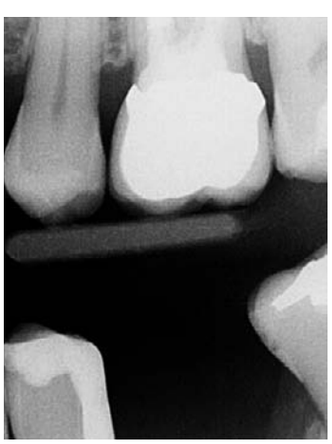
43.3 Perforation sealed with composite

Left: Prior to initiating the root canal treatment, the perforation has been sealed with a composite restoration. A second mesiobuccal canal has been detected and instrumented.

Middle: Four canals have been obturated.

Right: A fiber post has been placed in the palatal canal, and a build-up of composite core material has been constructed.





43.4 Follow-up

Left: Postoperative radiograph.

Right: At 6-month follow-up, a crown has been placed that encompasses the defect; the gingiva is free of inflammation and the patient is symptom-free.

Management of Perforations

The primary goal in management of perforations is to arrest the inflammatory process and the subsequent loss of tissue attachment by preserving healthy tissues at the site of the perforation. Many materials have been used to repair perforations, including: amalgam, Cavit (3M-ESPE, St. Paul, MN, USA), calcium hydroxide, super-EBA, glass ionomer, composite, gutta-percha, and zinc oxide eugenol cement. The success rate of these materials has been variable.

Since the introduction of MTA, substantial evidence has collected that it is the material of choice for perforation repair (Lee et al., 1993; Pitt Ford et al., 1995). It is biocompatible, provides a tight seal, and promotes the regeneration of cementum, thus facilitating the regeneration of the periodontal tissues. This characteristic differentiates MTA from other comparable materials.

Main et al. (2004) presented a series of cases that demonstrated consistent healing with the use of MTA as a perforation repair material. The main advantage of MTA is its long setting time; however, this makes the material unsuitable for the repair of supracrestal perforations. If MTA comes into contact with oral fluids, it will wash out before setting.

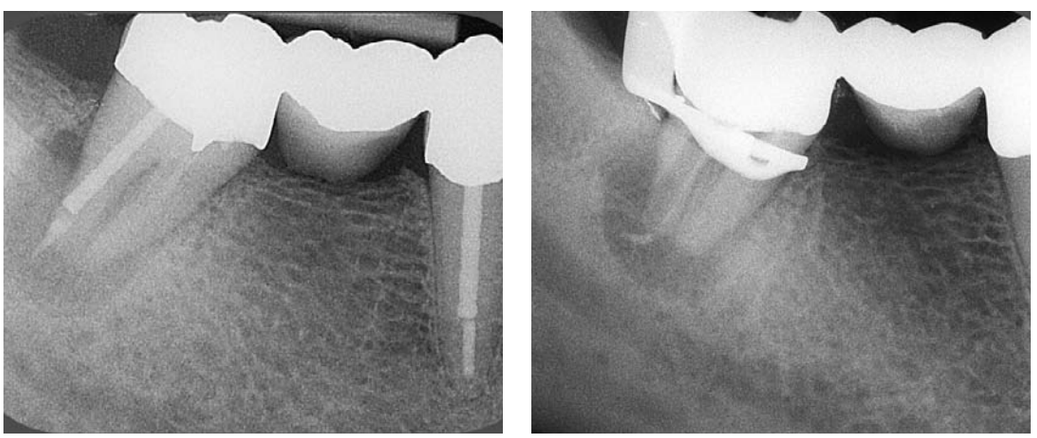
43.5 MTA

MTA is available in the original gray-colored preparation (left), and the newer white-colored version (right). The latter is indicated for esthetically demanding areas of the mouth. The main difference between the two varieties is that white MTA does not contain iron. Moreover, the handling characteristics have been improved in the white preparation. Numerous publications have reported that MTA and Portland cement are identical materials, except that bismuth oxide has been added to MTA to give the material its radiopacity (courtesy of Dentsply Maillefer).

43.6 Perforation after post placement in the apical segment of a root canal

Left: The patient presented with severe swelling and pain in the area of tooth 47. Radiograph showing a large radiolucency. The bridge had been seated several years earlier.

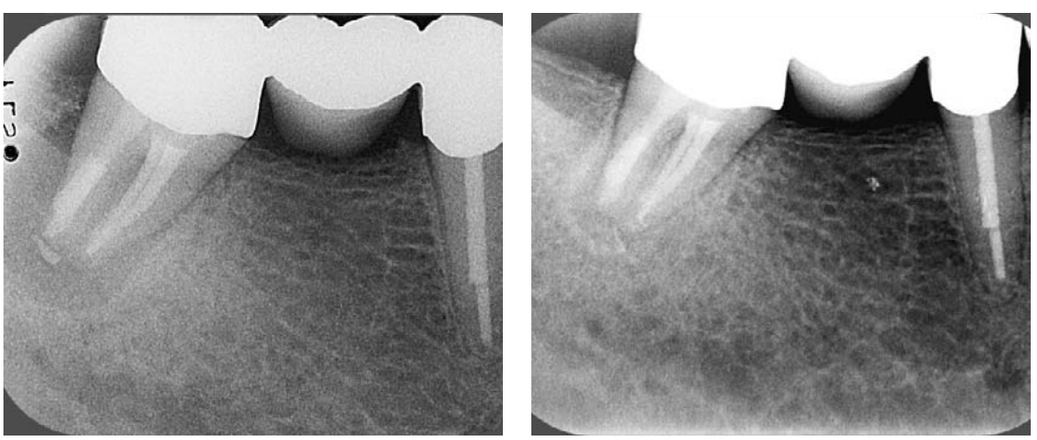
Right: An access opening was made through the existing abutment, and the post was removed with the use of ultrasonics. The root filling material from the mesial canals was also removed.



43.7 Repair of the perforation with MTA and follow-up

Left: The distal canal has been filled with an apical plug of MTA and the mesial canals with gutta-percha and sealer. At the second visit, the setting of MTA was confirmed and the access opening was restored with composite.

Right: 2.5-year follow-up radiograph showing progressive osseous healing.

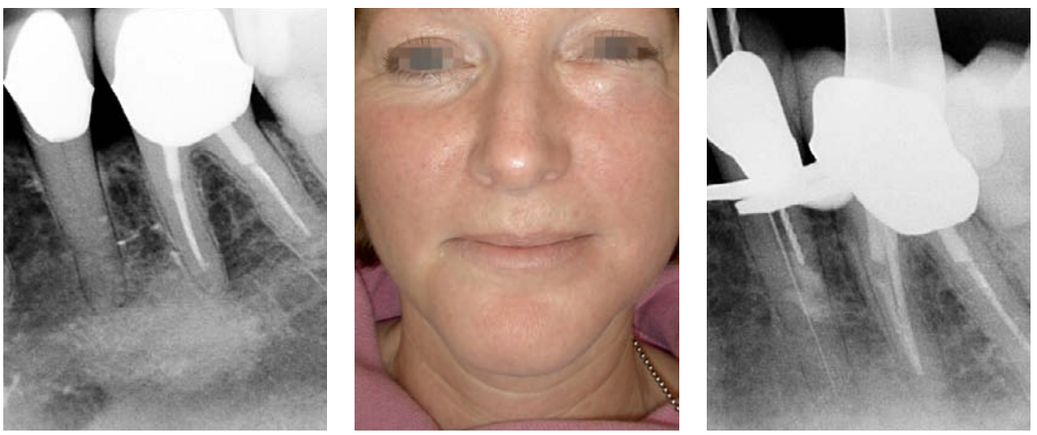


Additional Complications

A serious complication that may occur after creation of a root perforation is penetration of sodium hypochlorite through the perforation into the surrounding tissues (Neaverth and Swindle, 1990). The consequences of such an incident include an immediate burning sensation, severe pain, and marked facial swelling. In addition, it may lead to the subsequent development of a fistula, postoperative skin complications, ulcerations, and neurologic complications such as anesthesia, paresthesia (Reeh and Messer, 1989), and facial nerve weakness (Witton et al., 2005).

Whenever sodium hypochlorite has penetrated into the surrounding tissues, the dentist should inform the patient about the cause and nature of the incident. In many cases no, or only a minimal amount of, intervention is necessary. To relieve the acute pain, analgesics may be prescribed, together with cold compresses to reduce the swelling.

Antibiotics are recommended only in cases where there is a high risk of spread of infection. After the acute symptoms have resolved or diminished, endodontic treatment may be completed.

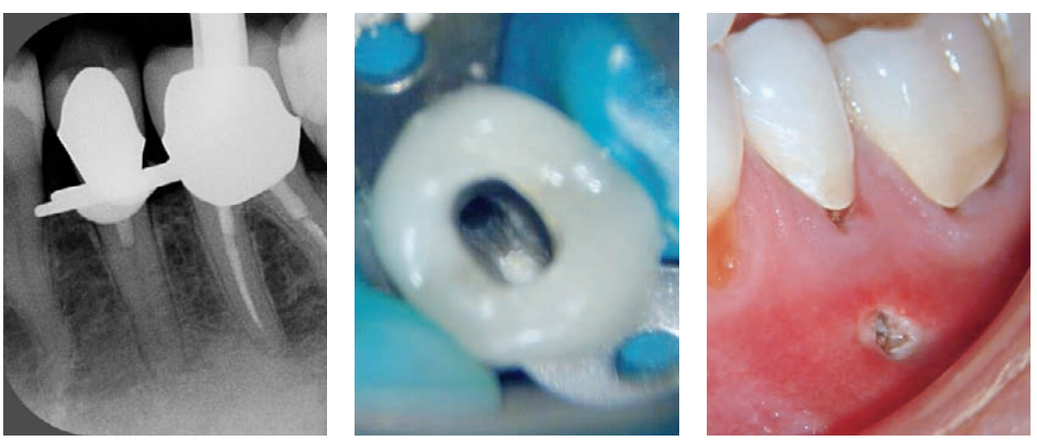


43.8 Midroot perforation and leakage of sodium hypochlorite

Left: Pulpitis in tooth 35. During an attempt at creating endodontic access, a perforation was created. The subsequent bleeding was mistaken for pulp tissue, and the dentist irrigated with sodium hypochlorite. After this, the patient experienced intense pain.

Middle: After removing the rubber dam, a pronounced swelling of the left side of the face became obvious.

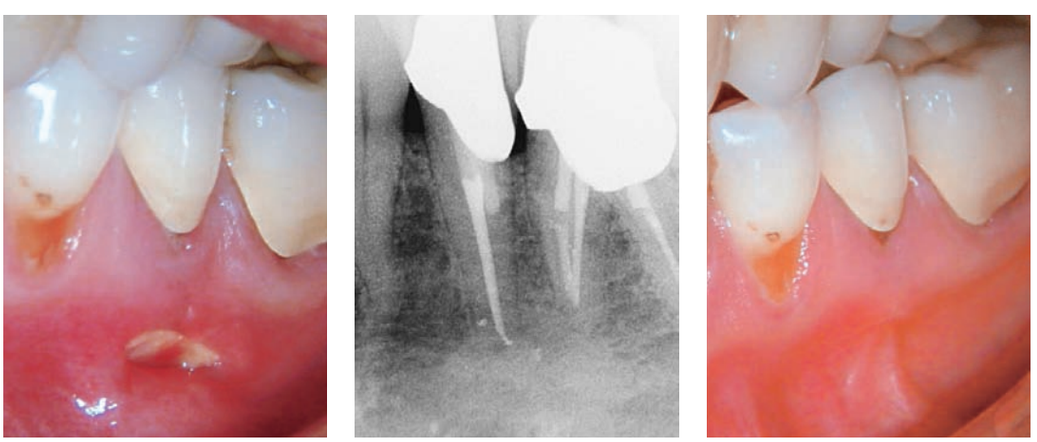
Right: The attending endodontist confirmed a perforation to be present on the buccal aspect; the distal file is placed within the perforation.



43.9 Perforation repair with MTA

Left and middle: After cleaning and shaping the canal, the perforation was closed with MTA, calcium hydroxide was applied, and the patient given another appointment.

Right: After 3 days the swelling had subsided, but the patient reported numbness on the left side of her face. The whole area was very sensitive to touch. Soft-tissue ulceration was present, which was curetted. Some necrotic tissue and remnants of set MTA were removed, and the endodontic treatment was completed.



43.10 Follow-up exam

Left: One week after finishing treatment, the patient reported that she was almost free of symptoms and that normal feeling had returned. The lesion probably originated from an area of necrosis, caused by leakage of sodium hypochlorite. The lesion in the oral mucosa is still visible, but shows signs of healing.

Middle and right: After 2 months, complete healing of the soft tissues has taken place. The patient is asymptomatic, and there are no probing depths of any significance.

Application of Mineral Trioxide Aggregate (MTA)

If the perforation is associated with a large osseous defect, it may be beneficial to use an extra-radicular matrix to prevent extrusion of the repair material. Most publications agree that using a matrix allows better control of the repair material (Lemon, 1992; Aldahainy and Himel, 1994). Whether this will result in a better treatment outcome remains to be demonstrated.

Matrix materials should be biocompatible and bioresorbable. A number of materials have been used as matrix materials, including tricalcium phosphate, hydroxyapatite, demineralized freeze-dried bone, collagen, and calcium sulfate.

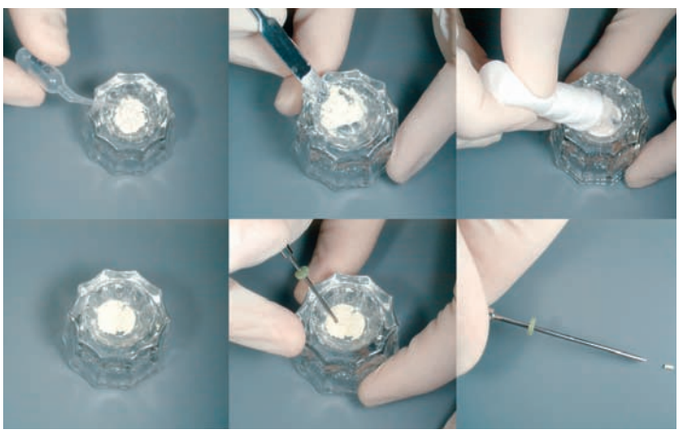
After controlling the hemorrhage, the repair material is placed using appropriate instruments. In the case of MTA, carriers or small spatulas are used to deliver the material to the perforation site. It has been shown that indirect ultrasonic activation of MTA results in a denser filling than with hand compaction (Yeung et al., 2006). This can be achieved by using a plugger to compact the MTA and having the dental assistant touch the plugger with an ultrasonic tip at the same time.

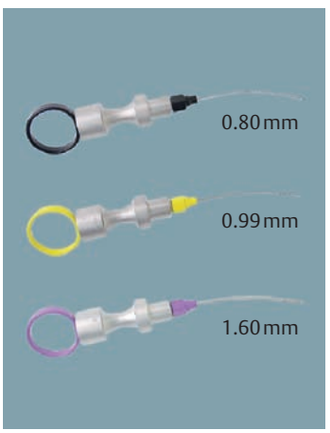
If MTA becomes too moist during compaction, thick paper points may be used to wick out the surplus moisture.

43.11 Armamentarium

The consistency of the mixture of MTA is critical for correct handling. It should have the consistency of wet sand, and the pellet that is extruded from the carrier should retain its form.

Right: Dovgan MTA carriers are available in three different diameters (ADS, Vaterstetten, Germany).





43.12 Perforation in the furcal floor of a maxillary molar, with attachment loss

Left: The patient was referred for retreatment of tooth 16. The radiograph reveals a periradicular lesion. A sinus tract was present, which was traced with a gutta-percha cone.

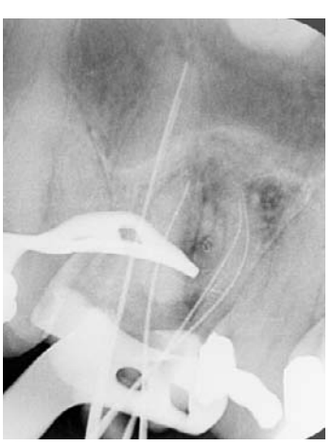
Middle and right: The presence of a sinus tract and pocket formation may indicate the existence of a perforation. In this case, a probing depth of 8 mm on the buccal aspect was observed.

43.13 Localizing the perforation

Left: After removal of the restoration, a perforation was made apparent by profuse bleeding from the floor of the pulp chamber.

Middle: The bleeding tissue was partly removed using an electrosurgical tip. After removing gutta-percha from the canals, a second mesiobuccal canal was identified.

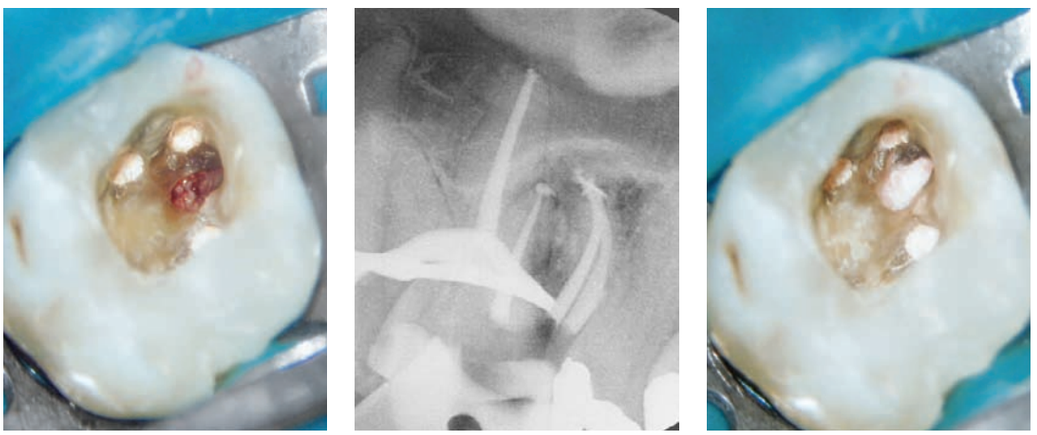
Right: After establishing working length with an apex locator and two radiographs, all canals were cleaned and shaped, and a dressing of calcium hydroxide was placed in the canals and the perforation site. A second visit was then scheduled.



Because MTA needs at least 3 hours to set, a moist cotton pellet is placed over the material and the tooth is sealed with a temporary restoration. On re-entry, MTA should be completely set and well fitted to the perforation site. Subsequently, the tooth should be definitively restored as soon as possible with an adhesive material to prevent coronal leakage.

Perforations in the furcation area of multirooted teeth are usually considered as crestal perforations, because of the close proximity to the epithelial attachment and possible communication with the gingival sulcus. According to Fuss and Trope (1996), the rate of success of their repair is low, because these furcal perforations are most susceptible to apical proliferation of epithelium and subsequent pocket formation.

However, Main et al. (2004) demonstrated that the use of MTA for repair of infected furcal perforations resulted in normal tissue architecture adjacent to the repair site after 1 year. According to the authors, the availability of MTA may require re-evaluation of previous guidelines regarding prognosis of perforated teeth.

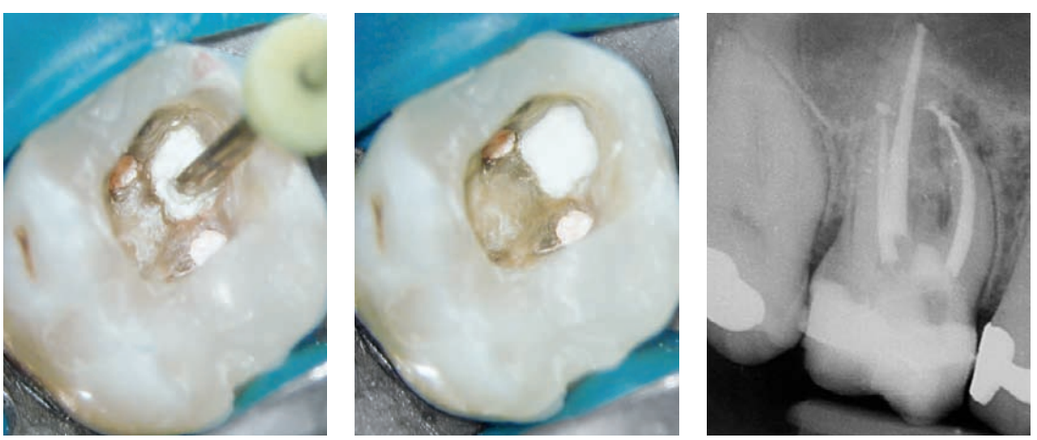


43.14 Obturation and application of a matrix of calcium sulfate

Left: Upon re-entry, the tissues in the perforation site exhibited superficial necrosis, due to the high pH of calcium hydroxide. Bleeding was negligible, and the outline of the perforation was clearly visible.

Middle: Radiograph showing obturation of the canals.

Right: After obturating the canals, an extraradicular matrix of calcium sulfate was placed in the perforation to recreate the external root contour and act as a barrier against which MTA can be applied.

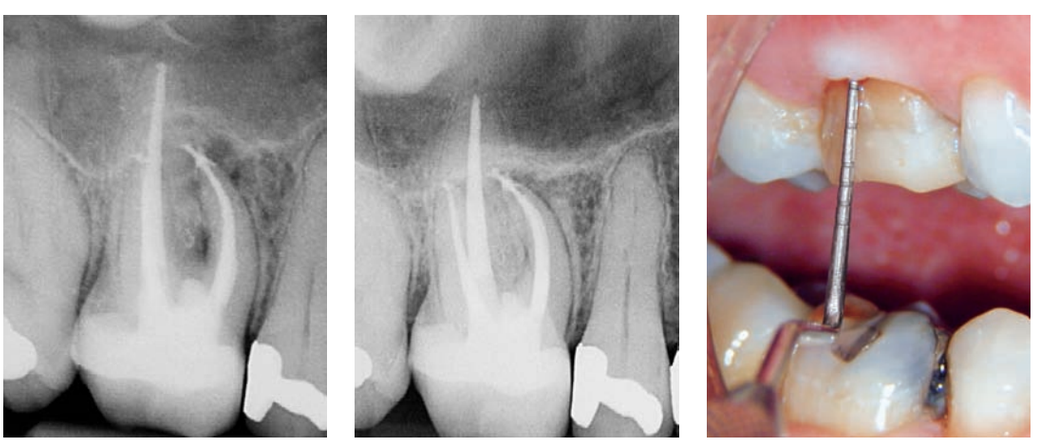


43.15 Perforation repair with MTA

Left: After setting of the calcium sulphate, which takes several minutes, MTA was applied with a carrier. It was compacted with pluggers and the blunt end of thick paper points to absorb the surplus moisture.

Middle: MTA applied to a thickness of 3 mm.

Right: Because MTA requires 3 hours to set, a moist cotton pellet was introduced on top of the MTA and the access was closed with a temporary restoration.



43.16 Definitive restoration with composite, and follow-up

Left: At the third sitting, a composite build-up was applied, after confirming the setting of MTA. In addition to an apical lesion, an interradicular lesion was visible on the postoperative radiograph, indicating bone loss in the furcation, which was probably caused by the longstanding perforation.

Middle and right: After 6 months, both the apical and interradicular lesions have decreased in size. The buccal probing depth has been reduced from 8 mm to 4 mm, indicating that reattachment has occurred.

Surgical Management of Perforation Defects

Whenever possible, nonsurgical repair is preferred in the management of perforations. An internal approach is usually less invasive and preserves the periodontal tissues. However, there are cases in which surgical intervention may be the treatment of choice. These include perforations in areas only accessible via surgery, perforations with a concomitant periodontal component, perforations that have not responded favorably to conservative therapy, and defects in which excessive amounts of a foreign body, such as obturating material, have been extruded (Regan et al., 2005).

In addition, there may also be ecologic factors that could tip the balance in the decision of which treatment option serves the patient best. If the defect is readily accessible surgically, and if disassembly of the existing coronal restoration would yield a significant risk and additionally high cost to the patient, then surgical repair may be considered. Some patients are treated best with a combination of a nonsurgical and surgical approach.

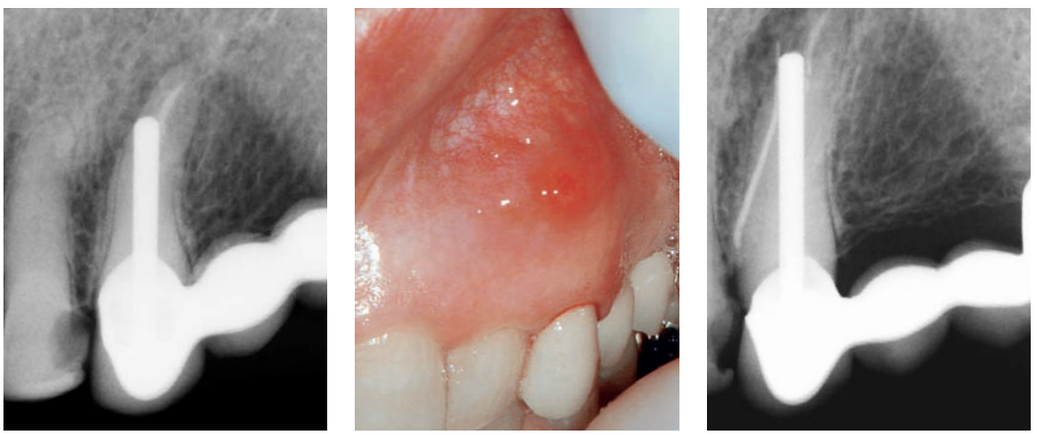
As a last resort, intentional replantation may be carried out in conjunction with perforation repair (Poi et al., 1999; Shuman et al., 1999).

43.17 Perforation of a fixed bridge abutment

Left: Radiograph showing a perforation by a misaligned post in an abutment tooth.

Middle: Sinus tract as a sign of apical periodontitis.

Right: Sinus tract traced with a gutta-percha cone. Because an internal approach to repair the perforation would have required disassembly of the four-unit bridge, surgical intervention was proposed (courtesy of Dr. Aye Min).

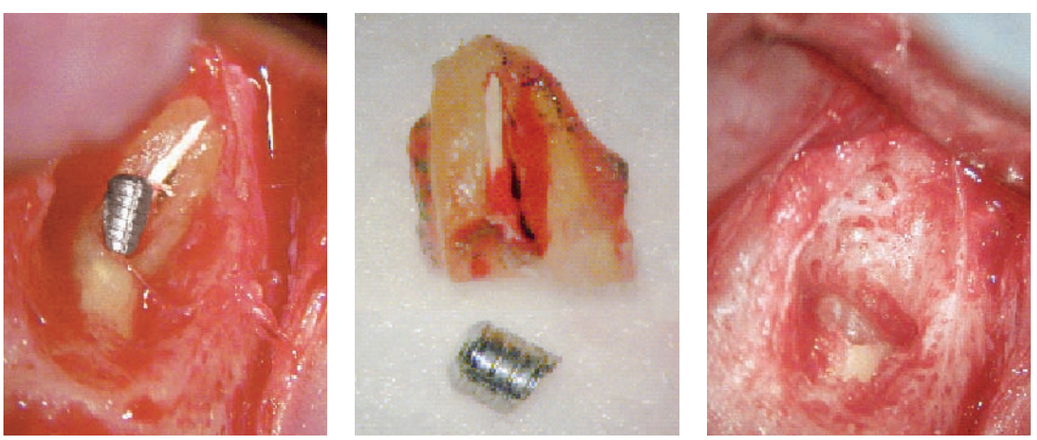


43.18 Surgical repair of the perforation

Left: Following flap refection and osteotomy, access was gained to the perforation site.

Middle: Root resection carried out at the level of the perforation.

Right: Root tip preparation completed to a depth of 3 mm (courtesy of Dr. Aye Min).

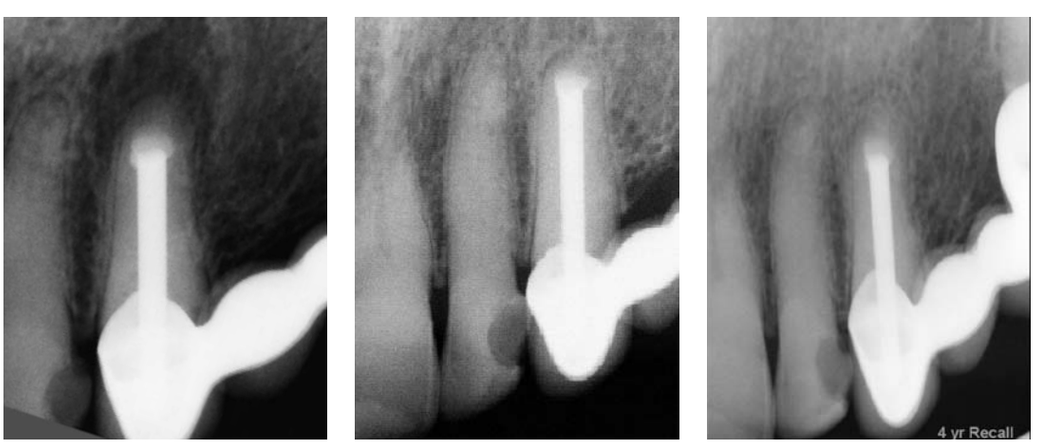


43.19 Follow-up

Left: Postoperative radiograph shows the MTA root tip filling.

Middle: One-year follow-up radiograph showing complete resolution of the lesion.

Right: Four-year follow-up radiograph, showing complete healing of the lesion, indicating that the patient is completely asymptomatic (courtesy of Dr. Aye Min).



44 Bleaching Discolored Teeth

Especially in the anterior segments, discolored endodontically treated teeth can present a cosmetic problem. As an alternative to the fabrication of full crowns or the use of composite resin or ceramic veneers, the dentist can use tooth bleaching as an esthetic treatment. The techniques for *external* bleaching of vital teeth have been described in various literature reviews (Attin, 1998; Wiegand, 2006).

For *internal* bleaching of nonvital endodontically treated teeth, the "walking bleach" technique has been recommended, in which a bleaching agent is put into the pulp chamber for a certain period. This procedure, which includes an intentional devitalization of vital, severely stained teeth to render possible intracoronal bleaching treatment, should only be undertaken after proper consideration of the possible risks, and the patient must be fully informed.

A possible cause for discoloration of nonvital teeth is vital pulp extirpation, or traumatically induced internal bleeding of the pulp, which can lead to diffusion of blood products into the dentinal tubules. Breakdown of blood via chemolysis leads to release of iron. This iron, in combination with hydrogen sulfide released by bacteria, lead to the formation of iron sulfide, which causes a gray discoloration of the tooth.

In addition to blood metabolic breakdown products, the breakdown products of proteins from a necrotic pulp can also cause tooth discoloration. This may also be the case when, following inadequate access cavity preparation, pulp tissue remnants remain within the pulp chamber, usually in the region of the pulp horns.

Discoloration of the crown of an endodontically treated tooth can also be caused by the root canal filling material itself. Also some medicaments (e.g., Ledermix) can cause tooth discoloration. Such tooth discoloration, depending on the responsible substance, can in some cases be effectively treated by bleaching (van der Burgt, 1986). It is worthy of note, however, that this does not hold true for discolorations caused by metal ions (silver pins, amalgam) (Glockner and Ebeleseder, 1993).

In the clinical investigations published to date, initial good results, that is, immediately following bleaching, have been reported. The optimum result is color consistency of the bleached tooth with its neighboring tooth. However, over the course of time, the tooth sometimes becomes darker again (Friedman, 1997). The current theory about the etiology of this subsequent darkening is a poorly sealed restoration that permits diffusion of pigments and penetration by bacteria.

It is interesting that the "success" of bleaching is usually more positively appraised by the patient than by the dentist or by the investigator in a clinical trial. In the published long-term studies spanning a timeframe of 8–16 years, success rates of 45%–93% are reported, but also included in these studies are cases where the color comparisons with adjacent teeth are not perfect but clinically acceptable (Attin et al., 2003; Amato, 2006).

Today, preparations containing hydrogen peroxide are the most commonly used bleaching agent. Depending on the pH value, light effects, temperature, presence of Ko-catalysts or metallic reactions, free hydrogen peroxide can release various radicals ($H^{\cdot}$, $O^{\cdot}$, $OH^{\cdot}$, $HO_2^{\cdot}$), hydroxyl (OH^-) or perhydroxyl ions (OOH^-), which are responsible for the oxidative or reduction and therefore bleaching characteristics of hydrogen peroxide.

Walking Bleach Technique

For the walking bleach technique, a mixture of sodium perborate (mono-, tri-, or tetrahydrate) and water (ratio: 2 g/mL) is recommended. This mixture will release hydrogen peroxide slowly. In comparison to higher concentration hydrogen peroxide solutions, the bleaching effect can in some cases be somewhat slower but results in the same effect. The use of a mixture of sodium perborate and water reduces the risk of the occurrence of cervical resorption.

Hydrogen peroxide released from bleaching agents is responsible for the transient reduction of retention of adhesives to enamel and dentin. For this reason, following bleaching, allow for an approximately 3-week interval before the insertion of an adhesive definitive restoration (Attin et al., 2004).

In both clinical studies and laboratory investigations, there was no significant reduction in fracture resistance of bleached tooth hard structure when compared with sound teeth. However, the risk of fracture is increased if the tooth was previously weakened by the aggressive physical removal of hard structure (e.g., discolored dentin).

44.1 Initial clinical appearance

The discolored left maxillary central incisor does not exhibit an inadequate restoration. Restorations with open margins must be replaced with well-sealed (even temporary) restorations so the bleaching agent can work optimally in the tooth.

44.2 Radiographic findings

Left: Before initiating bleaching, the root canal filling should be checked radiographically and, if necessary, reinstrumented.

Middle: Radiograph to determine the working length.

Right: Root canal filling after retreatment.

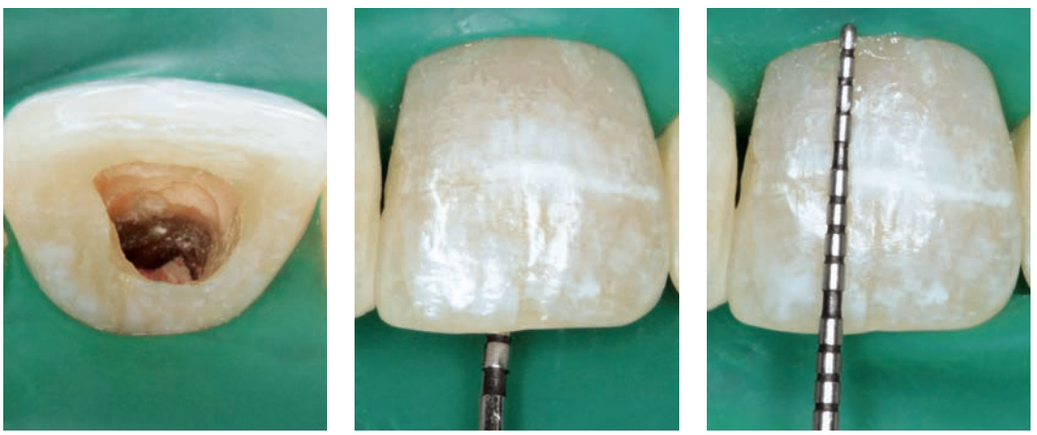
44.3 Preparing the working field

The area is isolated with rubber dam to minimize the risk of recolonization of the access cavity with bacteria, with the attendant risk of restaining. In addition, before using any bleaching agent or other solutions, the patient must be appropriately protected with a clinical napkin or cloth covering.

A potentially serious complication of the internal bleaching technique is the occurrence of external cervical resorption (Heithersay, 1999). Experimental studies have reported a rate of up to 7% (Freidman, 1997). Such cervical resorption is often only detected up to 7 years after the bleaching therapy, and the teeth are often symptom-free (Harrington and Natkin, 1979; Lado, 1983).

However, in animal experiments using an internal thermocatalytic bleaching treatment with heated 30% hydrogen peroxide, histologic signs of resorptive processes could be detected as early as 3 months after treatment (Rotstein 1991; Heller, 1992; Buchalia and Attin, 2006). Clinically, soft-tissue swelling was evident within the interdental papillae or the affected teeth were sensitive to percussion.

Cervical resorption often occurs on teeth that have undergone endodontic treatment because of dental trauma. Furthermore, studies have shown that an association exists between the application of heat (thermocatalytic method), the lack of cervical sealing, and the use of 30% hydrogen peroxide. All may be associated with the observed resorption (Madison and Walton, 1990).

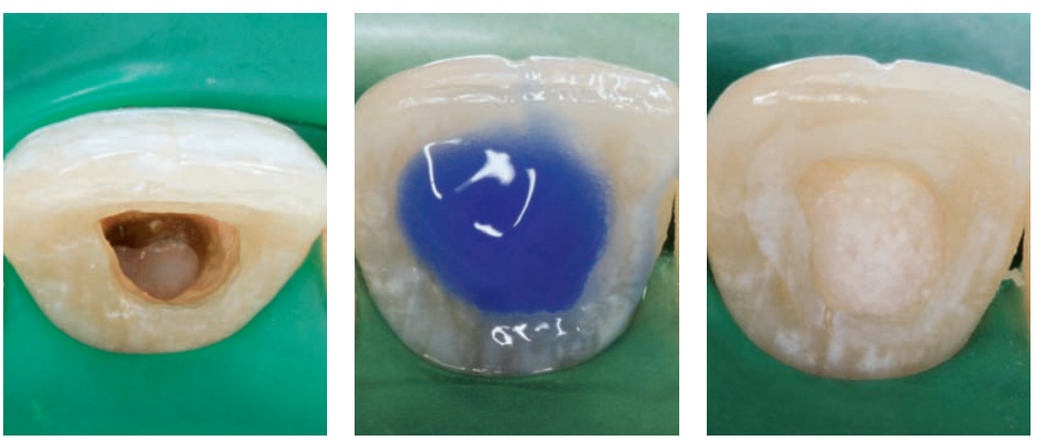


44.4 Access cavity

Left: The previously prepared access cavity is reopened. Cement or remnants of sealer are removed without sacrificing additional dentin. The original root canal filling is removed from the coronal end to a level 2 mm apical to the gingival margin.

Middle: The coronal position of the root canal filling is checked using a periodontal probe.

Right: Probing to check the coronal extent of the root canal filling from the labial aspect.

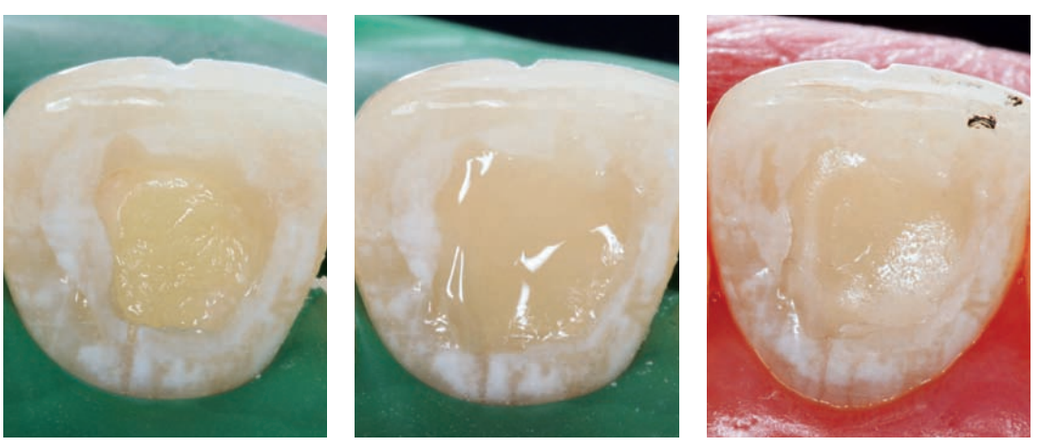


44.5 Walking bleach paste

Left: The cervical coverage of the root canal filling with glass ionomer cement ends at the height of the gingival margin.

Middle: To achieve retentive etching of the enamel and opening of the dentinal tubules, etching with 37.5% phosphoric acid for 15 seconds is recommended, with subsequent rinsing.

Right: The bleaching paste consisting of sodium perborate and water is applied to the dentin.



44.6 Temporary closure

Left: A foam pellet soaked with the bonding agent is placed on the bleaching paste and light-cured.

Middle: The composite restoration is applied on this base, and on the etched enamel surface.

Right: The tooth should be checked for premature contacts because the lack of internal stabilization in this phase of treatment can lead to coronal fracture.

44.7 Bleaching results

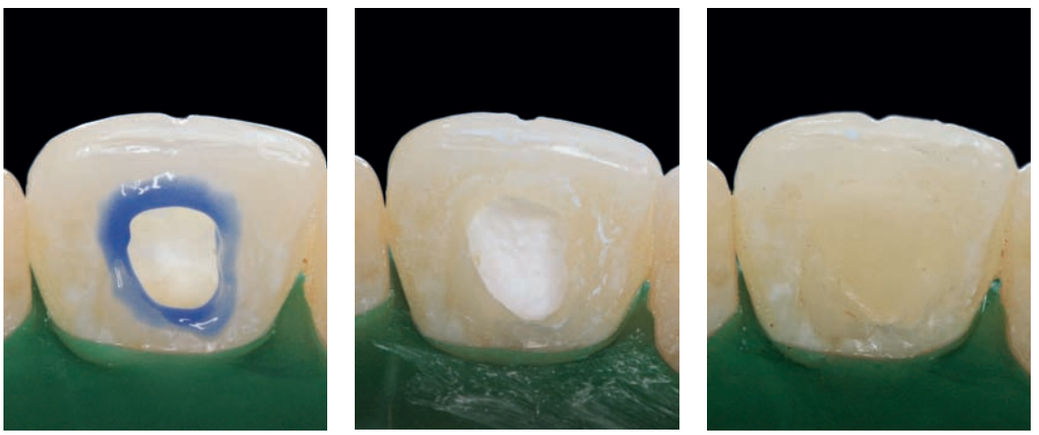
The bleaching paste remains inside the tooth for about 7 days. To avoid overbleaching, the patient must be instructed to observe the bleaching result at home, and when the color of the bleached tooth matches that of adjacent teeth to contact the dental practice. Depicted here is the result after 7 days of bleaching.

44.8 Calcium hydroxide

Left: After removal of the bleaching paste, the cavity is irrigated with 1–3% sodium hypochlorite, and the enamel margins are etched.

Middle: Calcium hydroxide paste is placed for a minimum of 7 days onto the dentin for neutralization.

Right: The cavity is securely closed and sealed temporarily with composite resin.



44.9 Final treatment

Following a waiting period of about 3 weeks, definitive treatment with an adhesive-bonded and internally stabilized restoration.

Left: Conditioning of the enamel.

Middle: Dentin conditioning using the “total etch” technique before applying the adhesive.

Right: Definitive composite resin restoration seated upon enamel and dentin.

44.10 Treatment result

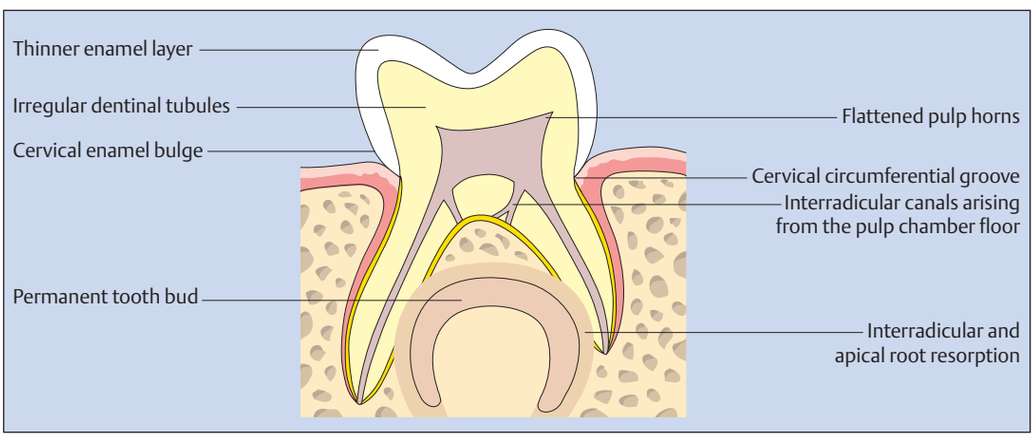
The follow-up six months later reveals a stable treatment result, and an acceptable lightening of the color of tooth 21, with good color matching to the adjacent teeth.

45 Endodontics in the Deciduous Dentition

Endodontic treatment of deciduous teeth is quite different from that of the mixed dentition or permanent teeth. This is due to the quite different morphologic/anatomic peculiarities of the deciduous teeth, and also often due to limited cooperation by the child patient. For example, 50%–70% of children under 5 years of age have untreated primary tooth caries, and within this group, 20% already exhibit the need for comprehensive dental treatment.

The high level of untreated and often progressive caries in primary teeth correlates with the high endodontic treatment needs of child patients. This is also directly due to specific anatomic characteristics of these teeth. Rapid progression of dental caries and early pulpal involvement in the deciduous dentition require a special treatment concept. The scenario is highly problematic in that it requires consideration of the psychologic components in addition to the pure dental findings and the stage of development of the entire dentition.

For this reason, the comprehensive treatment of the deciduous dentition necessitates giving a higher level of priority to the prevention of pain and infection, any space loss in the arches, and any other damage to the permanent dentition.



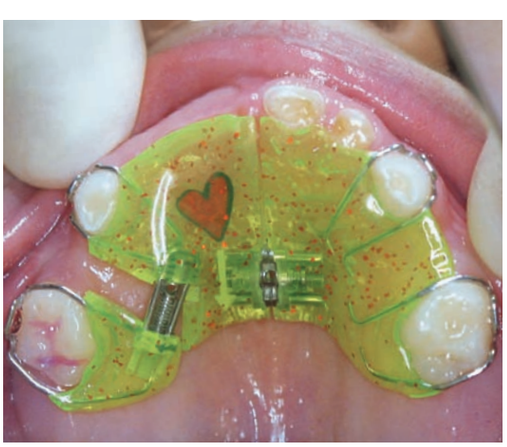
45.1 Deciduous tooth morphology

In comparison with the permanent dentition, the pulp of deciduous teeth relative to the tooth crown is larger. The thinner enamel layer, as well as the micromorphologic characteristics of the dentin, favors rapid spread of caries. In comparison with the tooth crown, the root is longer. The proximal contacts in the molar area are broad.

45.2 Value of the deciduous molars

Left: Importance of the second deciduous molar following loss of the first deciduous molar, for anchoring a space maintainer. Note that the permanent first molar is in the process of erupting.

Right: Root canal filling of the first deciduous molar for anchoring a so-called distal-shoe space maintainer following loss of the second deciduous molar.



45.3 Significance of the canines

Left: The primary canine has been described as the “pillar” of the deciduous dentition: It prevents mesial drifting of the molars.

Right: The strategically important canines and second molars should be retained whenever possible.

Goals and Diagnosis

Deciduous teeth play an important role in the growing child. In young children, maintenance of the anterior teeth is critical for speech development, especially learning sibilant sounds, as well as preventing the development of improper tongue function. Even in older children, molars, depending on the stage of development of the permanent teeth, are important as space maintainers for the permanent teeth. Additional goals include the maintenance of masticatory function, freedom from pain, and prevention of infections, as well as secondary damage to the permanent dentition. Direct evaluation of pain is particularly difficult with young children. Frequently, parents will report a child having sleepless nights or loss of appetite, which could be related to endodontic problems. Diagnosis of the problem in the responsible tooth is rendered more difficult because provocation of pain during vitality testing or percussion may lead to lack of cooperation by the child.

Tooth mobility tests, on the other hand, are useful and should be carried out in comparison of the contralateral tooth to exclude normal mobility before exfoliation. It is also helpful to carefully probe the furcation using a curved probe because the special anatomic characteristics (interradicular canals) can lead to tissue destruction in this area, which is a sign of infection.

45.4 Space deficiency

Left: Massive space loss occurred with subsequent crowding because of early loss of the first primary molar.

Right: Severely reduced masticatory function resulting from multiple primary tooth extractions can also have a negative influence on the child's nutrition. The esthetics are impaired, which could lead to psychological effects. The development of parafunctional oral habits is promoted.

45.5 Infections and possible consequences

Left: Buccal abscesses frequently resemble periodontal abscesses. The reason for this is infection in the accessory canals at the floor of the pulp chamber, which cause inflammation in the interradicular area. Note the mesial drift of the molar.

Right: So-called "Turner tooth" (tooth 24). Enamel defect as a result of chronic infection of the deciduous predecessor.

45.6 Clinical diagnosis

Left: The most important diagnostic criterion is the intensity of hemorrhage after opening the pulp chamber. This provides clues as to the extent of the inflammatory process. (Compare with the simultaneous access cavity preparation of teeth 84 and 85. Regarding therapeutic consequences, see "Summary and Conclusions" on p. 360.)

Right: An infection can spread into the furcation area via the interradicular canals. Following local anesthesia the furcation should therefore be carefully probed.

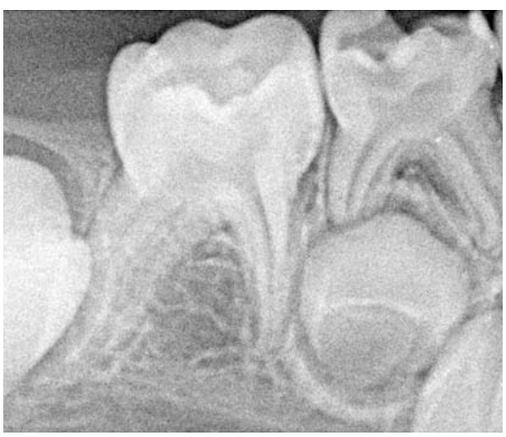
Radiographic Diagnosis

Between the ages of 4 and 4.5 years, the proximal surfaces of the deciduous molars come into contact, closing the usual moderate spaces between these teeth and thus increasing the likelihood of proximal caries development. If the child is cooperative, a radiographic diagnosis should be made, as the extent of caries is often clinically underestimated.

Radiographs also provide valuable clues to root anatomy, the progression of physiological root resorption already under way, the position of the permanent tooth buds, and possible pathologic alterations.

In contrast to the permanent dentition, infection-elicited osteolysis of deciduous molars usually occurs first in the furcation region due to the accessory canals on the floor of the pulp chamber. Differential diagnosis with regard to purely physiologic root resorption processes is not always simple, so additional clinical probing of the furcation using a curved (Nabors) probe is recommended.

As intraoral radiographs are sometimes not possible due to poor cooperation, or because of parental rejection of radiation exposure, alternative methods may be used, such as the cold light probe or laser assessments. Even with poor cooperation, children tolerate these examination methods better than intraoral radiographs.



45.7 Radiographic diagnosis

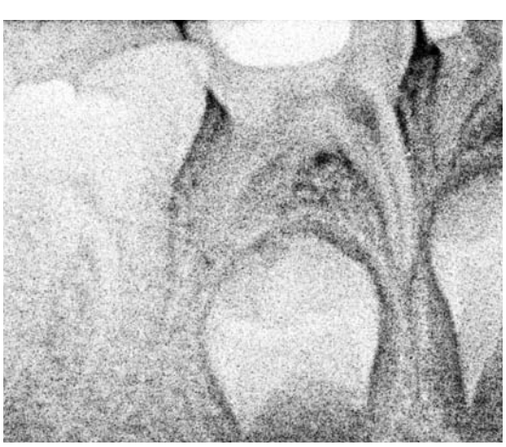
Left: Congenitally missing permanent second premolar. Dependent on the stage of development of the first permanent molar and other relative orthodontic considerations, the retention of the second deciduous molar is recommended.

Right: Anatomic variations such as three roots on a primary mandibular molar are a common occurrence in the deciduous dentition.

45.8 Radiographic diagnosis

Left: Typical interradicular radiolucency caused by infection from accessory canals on the floor of the pulp chamber.

Right: Periapical radiolucencies are quite rare and usually occur in cases with advanced stages of carious destruction of the crown.



45.9 Radiographic diagnosis

Left: Internal resorption is related to inflammation: Note the restoration near the pulp on tooth 85.

Right: External resorption is also related to inflammation.

Prerequisites for Pediatric Dental Treatment

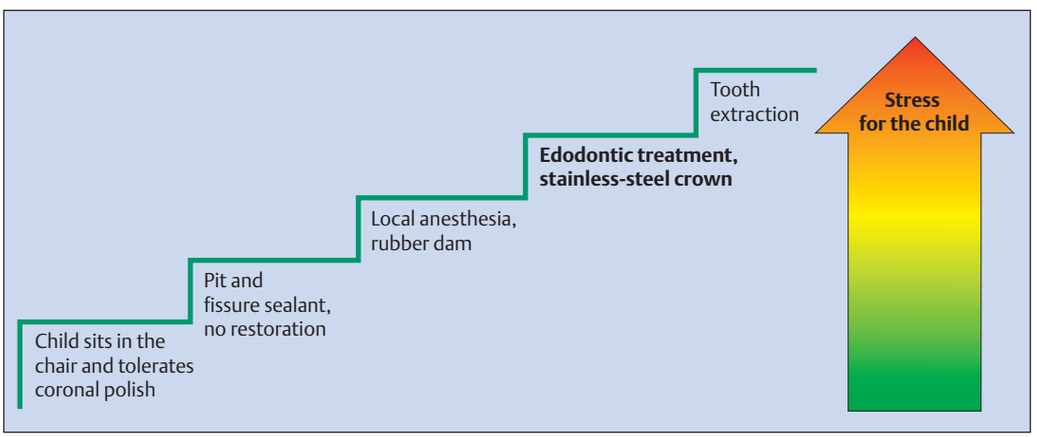
In addition to proper technique and diagnosis, endodontic procedures in the deciduous dentition depend above all on the child's level of cooperation. As cooperation is often impeded by acute pain, *early* treatment of deciduous tooth caries is especially important.

Children can gradually be introduced to treatment with the help of the "tell–show–do" technique. If acute pain and swelling with a tendency to spread are already present, the dentist may also consider prescribing antibiotics to protect the permanent tooth bud.

With very young children who remain noncompliant but are in pain, behavioral management alone may often be unsuccessful without medicinal support. In cooperation with an anesthetic team with pediatric experience, comprehensive dental treatment can be carried out under conscious sedation or, ultimately, general anesthesia.

45.10 Behavioral management

"Tell-show-do": First the instrument is explained and shown, then demonstrated on a finger, and only then applied in the mouth. Therapy takes place "from easy to difficult." In contrast to the treatment of adults, whenever possible the child's first experience should be a small or non-invasive procedure to build up the child's trust. Endodontic treatment is near the top of the ladder in the diagram.



45.11 Local anesthesia

Left: By using special techniques to distract the child, administration of local anesthesia usually presents few problems even in young children.

Right: Informing the parents about the danger of bite injuries is very important.

45.12 Rubber dam

The application of rubber dam is also necessary when treating the child patient endodontically. A compromise can be made by using the so-called "slit technique." This provides a relatively dry working field and prevents aspiration while retracting the soft tissues. The access to the interdental lesion is made easier.

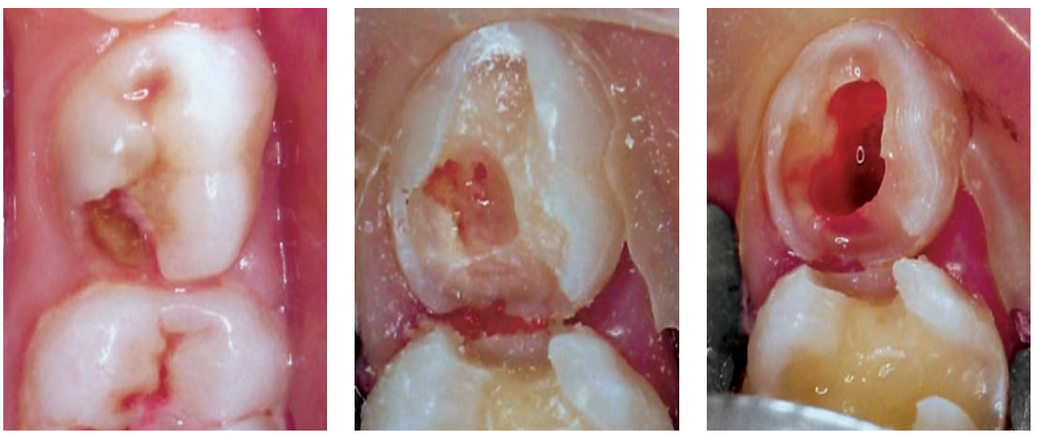
Therapy: Pulpotomy

During excavation of caries from deciduous molars, pulp exposure may occur very quickly. Even with a residual dentin thickness of approximately 1 mm, early involvement of the pulp and inflammation might be possible. Therefore, even in the presence of a tiny pulp exposure, amputation of the coronal pulp of molars is the treatment of choice, whereas on anterior teeth pulpectomy is preferred.

In the case of pulpotomy, the roof of the pulp chamber is removed after exposure of the pulp, using a high-speed bur under water cooling; at the same time the coronal pulp tissue is removed.

Until recently it was recommended to remove the pulp tissue using a slow-speed round bur or excavator, but this often led to the creation of a tear wound and therefore to prolonged bleeding. Critical for success is the *proper diagnosis*: The affected tooth should never have been associated with severe pain, it should not exhibit mobility (neither physiologic nor nonphysiologic), and there should be no sign of abscess formation.

Hemorrhage following access cavity preparation should be bright red and easy to stop. Finally, the tooth must be securely sealed with a restoration or, ideally, with a stainless-steel crown.

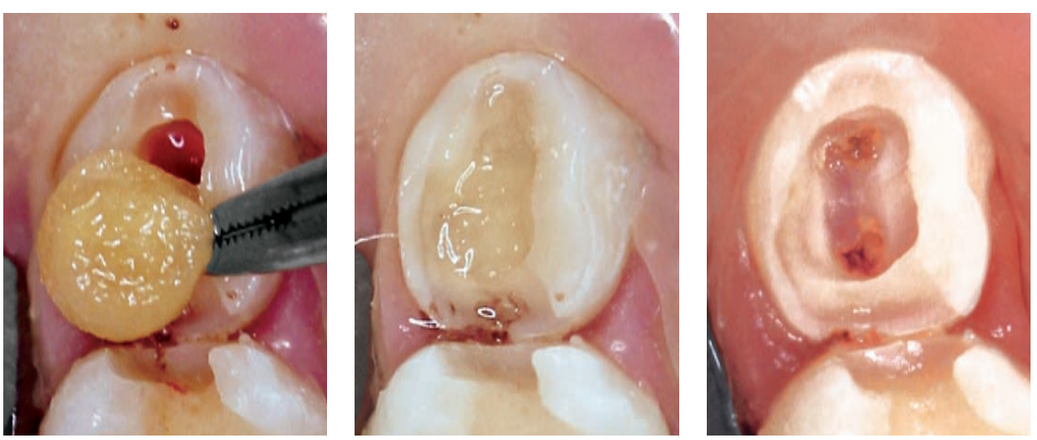


45.13 Pulpotomy, step I

Left: Initial clinical appearance. The extent of the caries supports suspicion of pulp exposure.

Middle: Opening the pulp chamber following caries excavation. The rubber dam was placed using the "slit technique."

Right: Following complete removal of the pulpal roof and the coronal pulp tissue, there is mild, bright red hemmorrhage.



45.14 Pulpotomy, step II

Left: Application of a cotton pellet soaked with 15.5% ferric sulfate solution.

Middle: The pellet should be changed several times, in order to keep the pulpal stumps in contact with fresh solution.

Right: Complete hemostasis should be achieved after approximately 15–30 seconds.

45.15 Pulpotomy, step III

Left: A thick mixture of polymer-reinforced zinc oxide eugenol cement (IRM) is applied.

Middle: Tooth preparation is carried out by reduction of occlusal height and proximal slicing mesially and distally. No preparation should be carried out on the lingual and buccal aspects so as not to endanger the retention of the stainless-steel crown.

Right: Final restoration using a prefabricated stainless-steel crown. A composite restoration is not recommended due to the eugenol content of the base filling.

Hemostasis and Covering the Pulpal Wound

Following administration of local anesthesia, a rubber dam should be applied in a child patient. This can be done using the so-called "slit technique" as described on page 354, which nevertheless necessitates good suction access and maintenance of a dry field. This prevents salivary contamination of the open pulp and inhibits taste sensation of the various solutions or irrigating agents used, any of which could reduce patient cooperation. Following the least traumatic method to sharply sever the coronal pulpal tissue, that is, using a high-speed bur above the canal orifices, hemostasis and covering of the pulpal walls are of critical importance for treatment success. The formation of a blood clot at the amputation site absolutely must be avoided, because this often leads to internal resorption and failure. Various agents for hemostasis and covering the remaining root tissue are available but have often been the subject of debate (see Fig. 45.16). As well as simplicity and speed of application, decisive factors include costs and, above all, the toxicologic safety of the material and clinical success rate.

Of critical importance for long-term success is a bacteria-tight and secure restoration, ideally with a stainless-steel crown.

45.16 Methods of hemostasis and coating the pulpal walls

Hemostasis	Covering/coating the pulpal wound
The *formocresol technique* (Buckley solution) is no longer recommended, because of the proven distribution of formaldehyde into surrounding tissues.	*Calcium hydroxide* is a promising treatment exclusively for accidentally exposed pulps, vital pulp, symptom-free teeth, and a sterile operating environment.
15.5% *ferric sulfate* in an aqueous solution is placed in the pulp chamber on a cotton pellet to stop any bleeding (hemostasis). Currently this is the method of choice.	*Polymer-reinforced zinc oxide eugenol cement* (IRM = intermediate restorative material) is still the material of choice today. Some still consider the eugenol component a potential problem.
Additional procedures (for which, however, no long-term studies exist) include the use of laser, BMP (bone morphogenic protein), or electrosurgery. *Alternatively,* hemostasis can also be achieved by applying pressure to a cotton pellet.	*Mineral trioxide aggregate (MTA)* demonstrated very positive results in initial studies and will likely replace other materials in the future. Problems include high costs and the discoloration of treated teeth.

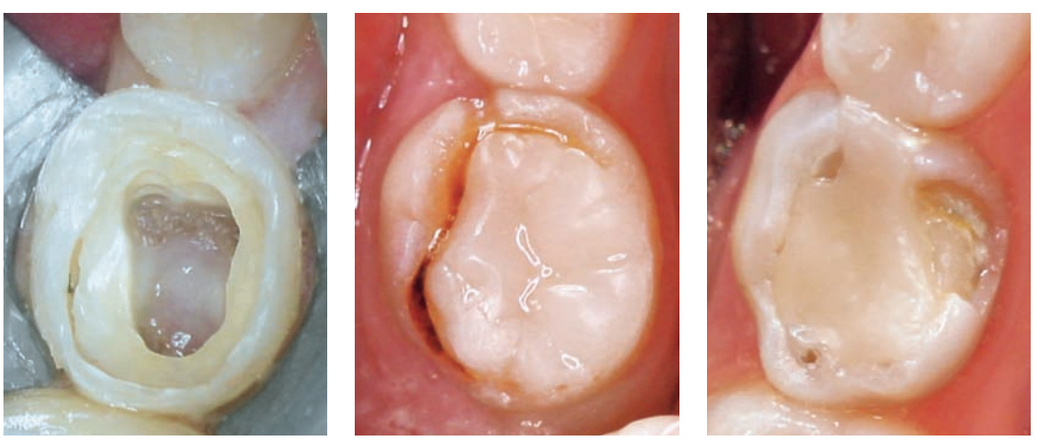
45.17 Hemostasis and capping

Left: Hemostasis with a cotton pellet soaked in 15.5% ferric sulfate solution. The pellet can be changed numerous times to wash out all blood clots. Following hemostasis, the remaining tissue remnants can be rinsed out using saline solution.

Middle: Mixture of IRM cement. Thicker consistency can be achieved by hand mixing.

Right: The material can then be formed into a cone to simplify placement of the material into the cavity with a ball burnisher.

45.18 Secure closure



Left: Clinical view following caries excavation and hemostasis in tooth 75. Capping using IRM and glass ionomer cement; closure using a multilayered composite restoration.

Middle: 2.5 years later, note the obvious marginal gap and fracture of the lingual wall. The restoration itself is intact. Possible cause is the eugenol component or the unfavorable C-shape of the cavity.

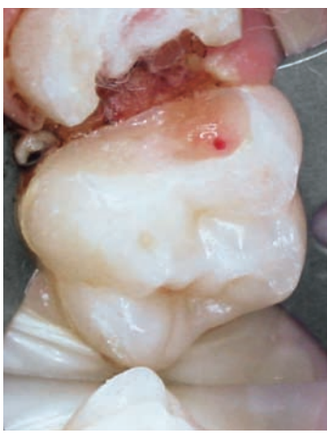
Right: Postendodontic fracture of the lingual wall following definitive closure with composite.

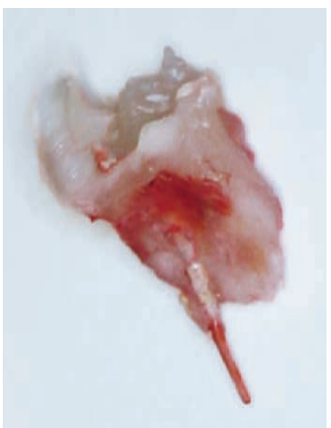
Contraindicated Treatments

Owing to the peculiarities of the deciduous tooth pulp, some measures which lead to success in permanent dentition fail in primary teeth. Even with pinpoint pulp exposure, undifferentiated mesenchymal cells are activated, which can lead to internal resorption and to subsequent failure. Because of the microstructure of the deciduous tooth dentin, bacterial invasion may have occurred even when the residual dentin thickness is maintained at about 1 mm; which is why even indirect pulp capping is frequently associated with clinical failure.

Simply opening carious primary molars and leaving them unrestored is not indicated. It can lead to tipping or migration of the adjacent teeth, as well as the development of hyperplastic pulpitis. In terms of hygiene, such a tooth represents the danger of a bacterial or fungal reservoir with possible damage to the permanent tooth bud; these teeth are not indicated as "space maintainers."

Similarly, the treatment of deciduous teeth with nonresorbable materials such as gutta-percha is contraindicated. This can lead to inflammation within affected deciduous teeth and resultant permanent tooth bud damage (Turner tooth), as well as inhibit tooth eruption or cause deflection of the permanent tooth from its normal eruption path.





45.19 Contraindicated treatments

Left: Even with only a small area of pulp exposure, direct pulp capping holds little promise of success.

Middle: Mesial drift of the tooth adjacent to a ground-down tooth. A pulp polyp has formed as well as niches for plaque accumulation.

Right: Nonresorbable materials such as gutta-percha must never be used on primary teeth. This leads to massive inflammation and the danger of permanent tooth bud damage.

Problems and Failures

The extent of caries in deciduous dentition is usually clinically underestimated. Most often failures following pulpotomy result from an incorrect diagnosis. Using inappropriate materials or an incorrect treatment sequence can also lead to problems. Secure sealing of an endodontically treated primary tooth is of utmost importance.

Therefore, the prefabricated stainless-steel crown is highly recommended for the permanent postendodontic restoration of deciduous molars. Compromises such as an insufficiently dry working field can be avoided by careful planning and successful estimation of the child's likely level of cooperation and compliance. Compromise treatments are only acceptable as a temporary solution, or in cases where the permanent tooth is soon to erupt.

If endodontic treatment fails due to a questionable indication or poor cooperation, leading to pulp necrosis or abscess formation, there may be an increase in the oral bacterial population, which can also negatively influence the permanent teeth.

45.20 Failures

Left: Zinc oxide eugenol cement placed deep in the canal of anterior teeth can lead to resorption problems.

Middle: The formation of a blood clot at the amputation site using the calcium hydroxide technique can lead to internal resorption.

Right: Ectopic eruption of the permanent tooth as a consequence of interradicular osteolysis.

Therapy: Pulpectomy

Deciduous Molars

Removal of the radicular pulp is indicated if, following access cavity preparation and removal of the coronal pulp, dark-colored, difficult-to-stop bleeding occurs or if repeated application of ferric sulfate solution does not stop the hemorrhage. These are signs of advanced pulpitis.

The goal is to remove the radicular pulp, to cleanse the canals, and to disinfect the canals by thorough irrigation. A "classic" preparation is not carried out. The determination of working length depends on the stage of development of the permanent tooth and is only possible to a limited degree by means of radiographs because of interradicular resorption. In addition, there is the danger that the child would close his or her mouth, leading to overinstrumentation and resulting in tooth bud damage.

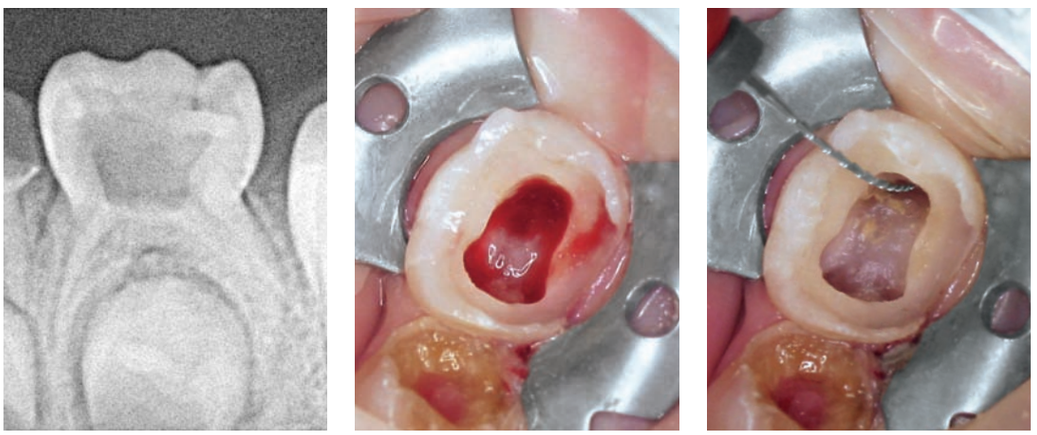
Electronic length determination can be helpful in such cases. A general rule is that the canal should not be prepared deeper than about 10 mm with instruments. Garcia-Godoy (1999) found significantly better results with overfilled than with underfilled canals. In contrast, overinstrumentation with files can lead to damage to the permanent tooth bud.

45.21 Pulpectomy, step I

Left: Pretreatment radiograph. The primary first molar is not worth maintaining; the primary second molar therefore plays a particularly strategic role in facilitating the correct eruption of the first permanent molar.

Middle: Access cavity preparation and caries excavation. The strong flow of dark red blood indicates infection of the root pulp.

Right: Removal of pulpal remnants and cleansing of the canal with a Hedström (H) file.

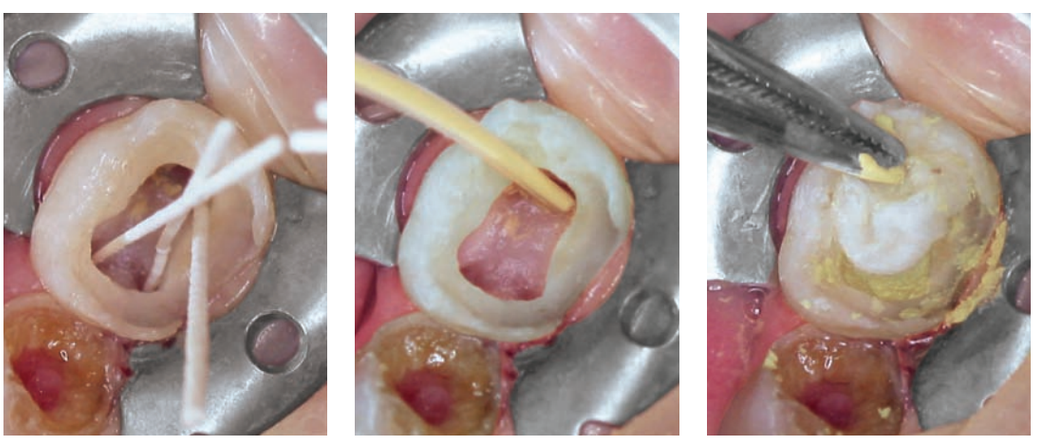


45.22 Pulpectomy, step II

Left: Irrigation with 1%–3% hypochlorite and saline solution, as well as drying the canal and control of hemostasis.

Middle: Filling with resorbable iodoform–calcium-hydroxide paste. Use of pure calcium hydroxide leads to premature resorption.

Right: Using a moist cotton pellet, the material is additionally directed apically.

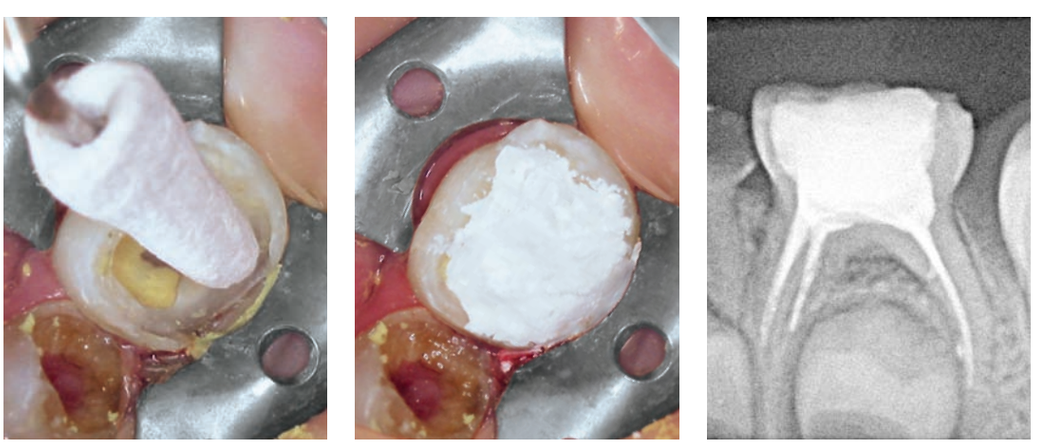


45.23 Pulpectomy, step III

Left: Build-up using zinc oxide eugenol cement.

Middle: The tooth is prepared for a stainless-steel crown.

Right: Radiographic check before further treatment to make any necessary immediate revisions.



Deciduous Anterior Teeth and Attendant Problems

After exposure of the pulp chamber of an anterior deciduous tooth, pulpectomy is the method of choice. Pulpotomy is not indicated for primary incisors as there is usually no way to distinctly differentiate between crown and root pulp. Also, with deeper amputation disturbances, resorptive processes can occur if nonresorbable materials are used. The treatment of anterior teeth is based on the length of time the tooth is expected to remain and the restorability of the clinical crown.

Attempting to save anterior teeth in young children is worth the effort from both the esthetic and speech development viewpoints. The procedures are similar to those described for deciduous molars. After the age of 5, the indication for pulpectomy must be carefully considered on the basis of the anticipated exfoliation date and root resorption, as well as the limited dental significance of the deciduous anterior teeth.

Furthermore, deciduous anterior teeth can easily be replaced via a removable prosthesis. In the case of poor patient cooperation, minimal remaining tooth structure following excavation and access cavity preparation, or in cases of extensive gingivitis that may compromise adhesive restorations, extraction of primary incisors may often be the better choice.

45.24 Length determination

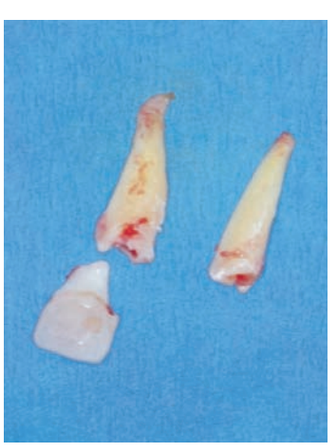
Left: Massive overfilling of iodoform–calcium-hydroxide paste in tooth 75. The tooth was subsequently restored with a stainless-steel crown.

Right: Radiographic follow-up 6 months later. The extruded material at the apex has been completely reabsorbed.

45.25 Problems with primary anterior teeth

Left: Ideally, the pulp can be extirpated in toto. Subsequently, the canal must simply be cleansed of blood and tissue remnants, and irrigated. Classic endodontic instrumentation is not carried out.

Right: Initial radiograph (left) and final radiograph (right). The final adhesive restoration can follow after covering the soft root canal filling material with glass ionomer cement. In such cases, primary tooth strip crowns filled with composite resin material are indicated.



45.26 Problems with anterior teeth

Left: Young children, in particular, frequently experience accidents during play, which increases the risk of fracture of endodontically weakened teeth. This anterior primary tooth trauma was caused by a blow to the upper lip by a swing. Initially the entire anterior segment was endodontically treated and the teeth restored using strip crowns.

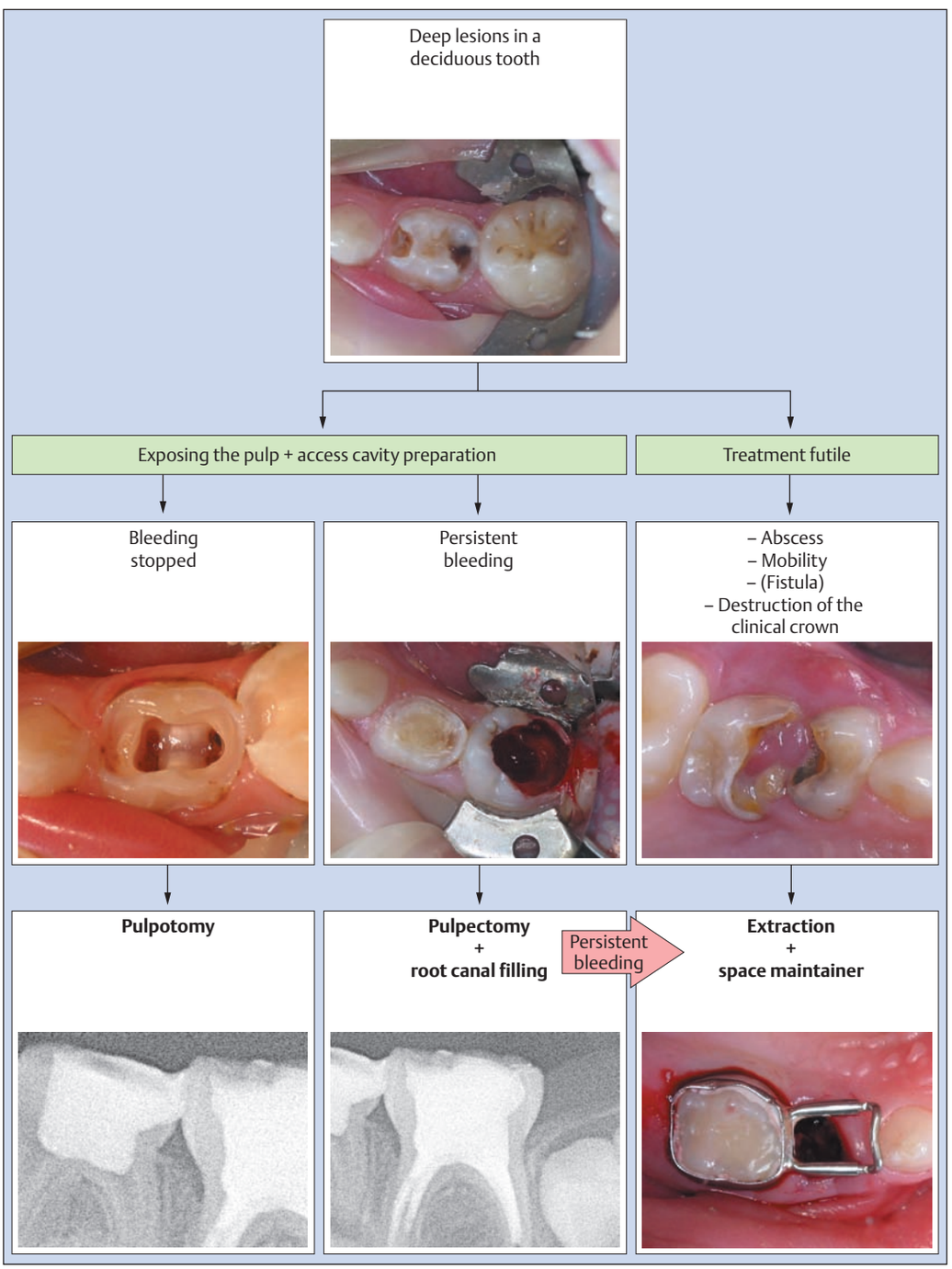
Right: The teeth of the same patient after extraction. Crown-root fracture. Note also that the adhesive bond of the strip crown has remained intact.

Summary and Conclusions

The decision concerning when to perform pulpotomy, when to perform pulpectomy, or if a tooth should be extracted is made after consideration of numerous factors. These include: pain diagnosis, mobility, radiographic findings (interradicular radiolucencies, resorption), fistula, abscess, cooperation and age of the child. Frequently the definitive diagnosis is only possible after clinical examination.

If, after opening the pulp chamber, only slight hemorrhage occurs and there is no pain, the tooth can be treated with pulpotomy. However, if bleeding following access cavity preparation and removal of the entire coronal pulp does not cease within a short period, or if the blood is dark red, then pulpectomy and root canal filling with a resorbable material is indicated.

If bleeding does not cease following extirpation and irrigation, or if the tooth exhibits increased mobility or an abscess, extraction is indicated. If the prognosis for a tooth is critical, extraction and subsequent treatment using a space maintainer can be attempted. On the other hand, it is unreasonable to leave carious teeth or teeth with open cavities in situ as "space maintainers."



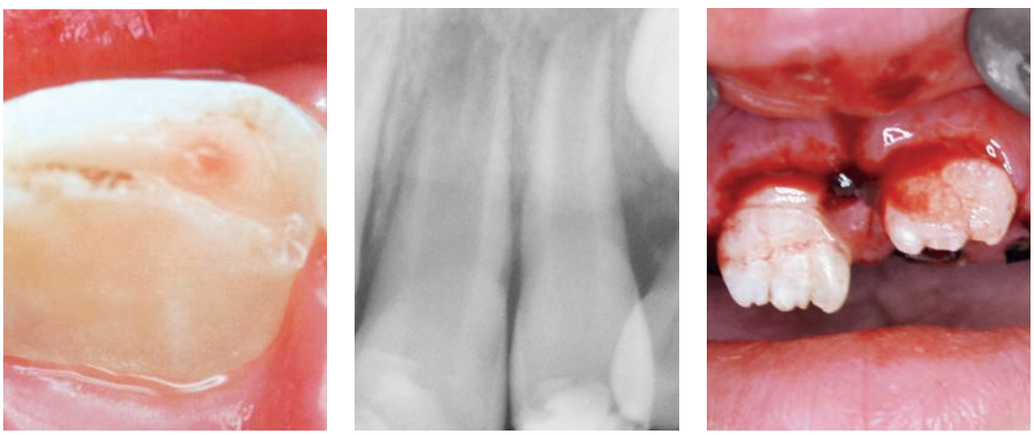
45.27 "Decision tree" for primary tooth endodontics

46 Endodontics in the Mixed Dentition

Endodontic treatment in the mixed dentition involves the treatment of permanent teeth with incomplete root formation, a clinical situation that one often encounters in patients between 5 and 13 years of age. Following eruption of a tooth, it is another few years before root formation is complete and the apex is definitively developed. These teeth have a very high regenerative potential; however they can show an extreme reaction when exposed to infection.

The necessity for endodontic treatment in the anterior segment is usually associated with a complex posttraumatic situation. In the posterior segments it is usually the first molars that become problematic because of the effects of early caries or rapid posteruptive tooth substance loss due to disturbances of enamel formation (e.g., molar–incisor hypomineralization [MIH]).

Endodontic treatment is rendered more difficult by the usually irregular canal lumen and the lack of the apical barrier. Especially in younger children, limited cooperation must also be taken into consideration. If molars are affected, an orthodontist should be consulted before initiating endodontic treatment in order to clarify any possible space problems and the necessity for orthodontic extractions. In these cases, preferably deeply carious first molars should be extracted rather than sound premolars.

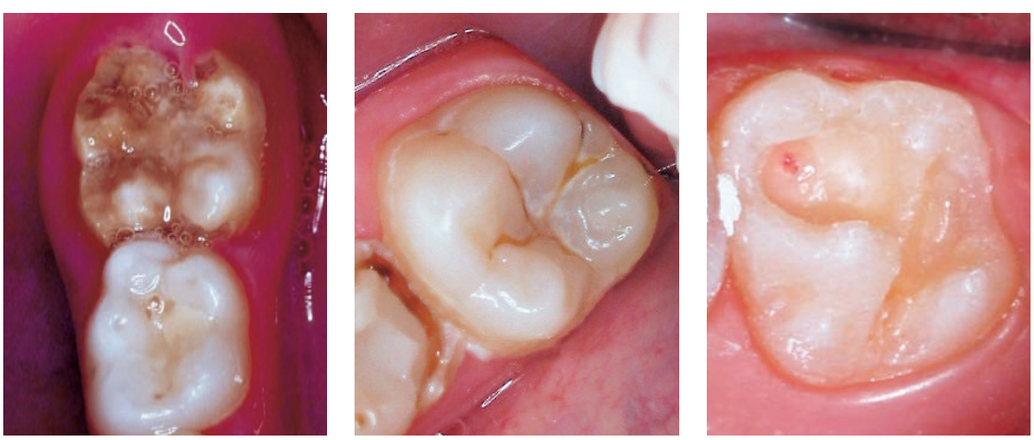


46.1 Anterior teeth

Left: Pinpoint pulpal exposure. The size and duration of pulpal exposure are decisive factors for further treatment.

Middle: Apical radiolucencies can be transient following trauma, and are referred to as “transient apical breakdown.” They must be differentiated radiographically from inflammatory induced alterations.

Right: Percussion or sensibility tests are not reliable indicators immediately following trauma, but should be regularly done during the course of treatment.

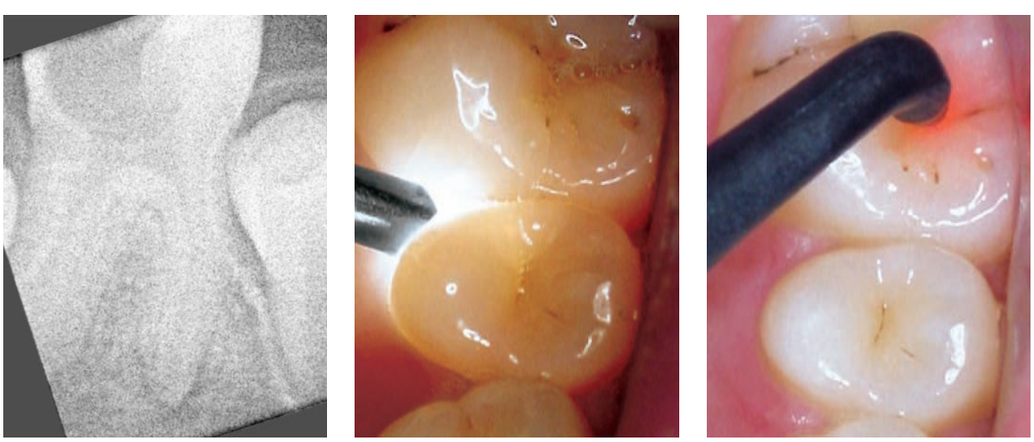


46.2 Molars

Left: Enamel malformations such as MIH can lead to early pulp exposure and the necessity for endodontic therapy.

Middle: A special problem is that of so-called “hidden caries”: intact enamel masks an extensive area of dentinal caries.

Right: During caries excavation, the pulp was exposed at the base of the cavity. The type of treatment for such an exposure depends on its size.



46.3 Caries diagnosis

Left: Advanced caries. Radiographically it is often difficult to differentiate between periapical radiolucency and incomplete root development.

Middle and right: Early diagnosis is of special importance. Alternative methods include transillumination (middle) or laser-based caries detection (right).

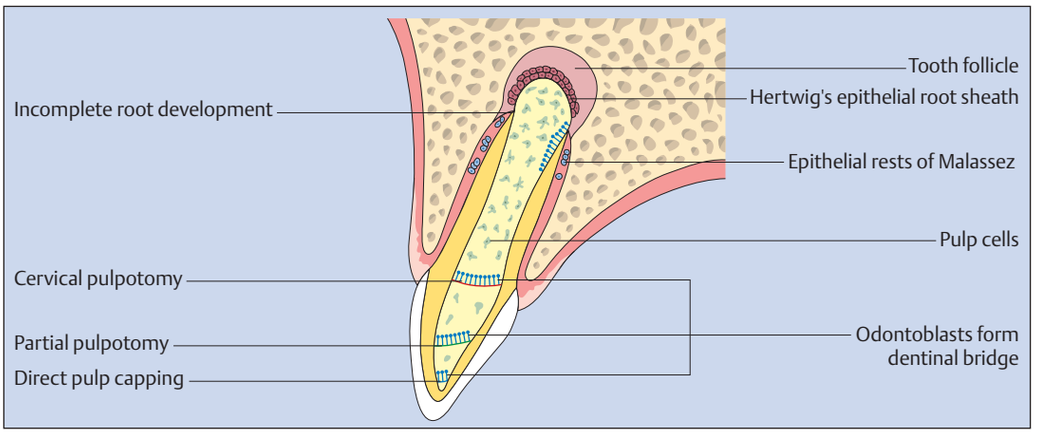
Methods for Maintaining Tooth Vitality

The regenerative potential of the young pulp is extremely high, so that following indirect or direct pulp capping with calcium hydroxide, there is a good chance of subsequent hard-tissue deposition and therewith maintenance of pulp vitality. A more extensive pulp exposure can be treated by means of pulpotomy (similar to deciduous teeth).

Retention of the radicular pulp will ensure completion of the root development. In order to protect the pulp from contamination, an absolutely dry working field is critical. If the pulpotomy is successful, conventional root canal treatment will not be necessary later on.

46.4 Histologic structures in teeth exhibiting incomplete root development

Direct pulp capping is only indicated in teeth with small (pinpoint) pulp exposures and a healthy pulp. If carious but hard dentin is left behind, a calcific bridge develops after several months. At a second visit, the clinician must then reexcavate the cavity and provide a reliable seal.



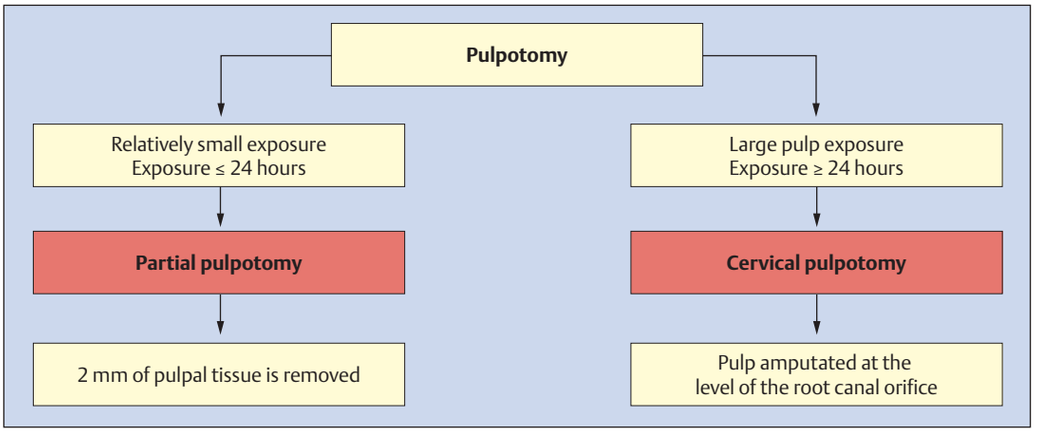
46.5 Cervical pulpotomy

Left: Initial situation. Deep carious lesion on a lower left permanent molar with incomplete root development.

Right: Cervical pulpotomy. If the tooth remains symptom-free, conventional root canal treatment is not necessary following completion of root development.

46.6 Pulpotomy

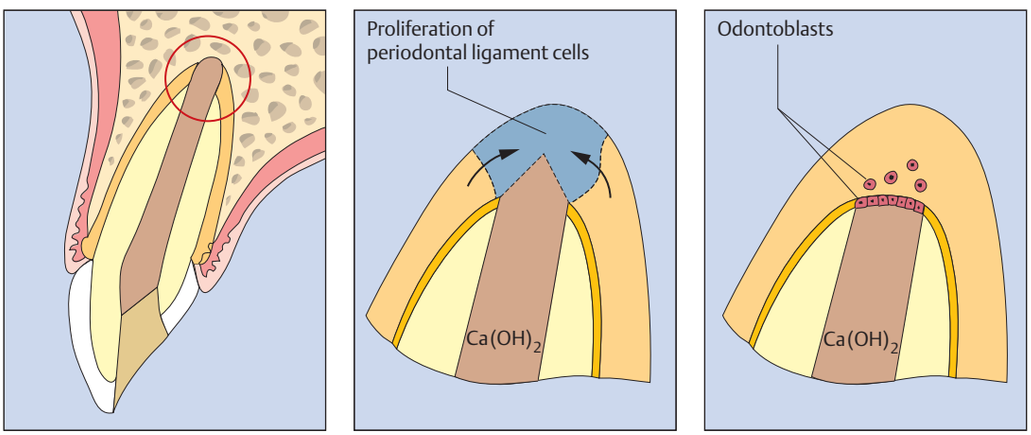
Any contaminated coronal pulp tissue is removed. With a small pulp exposure or exposure over less than 24 hours, partial pulpotomy according to Cvek can be carried out. Based on the assumption of the expected bacterial invasion depth, about 2 mm of pulp tissue is removed. With a cervical pulpotomy, the amputation site should be at the height of the root canal orifices. Following hemostasis using sterile saline solution, the amputation wound is first covered with calcium hydroxide and then with appropriate restorative material.



Apexification

If pulpal necrosis occurs in a tooth with incomplete root development, timely treatment is indicated. An acute abscess or external resorption can occur particularly rapidly because of the reactive nature of the young cells. However, classic endodontic treatment is rendered more difficult because of the inverted funnel-shaped canal lumen and the lack of an apical constriction. In such cases, "apexification" is the treatment of choice.

The procedure involves removal of necrotic tissue and careful cleaning of the canals without unnecessarily weakening the root. The calcium hydroxide dressing that is placed next stimulates the formation of a hard-tissue bridge. The length of the apexification treatment depends upon the stage of root development and the age of the patient, and is generally cited as 1 year on average. Thereafter, the root can be filled using gutta-percha and sealer. The success rate for apexification is between 74% and 96% (Cvek, 1993; Andreasen, 2000). The hard-tissue barrier may form not only apically but also *within* the canal, and vary greatly in its histologic composition. The success of endodontic treatment is generally good, but there is an increased danger of root fracture because of the thinner root canal walls.

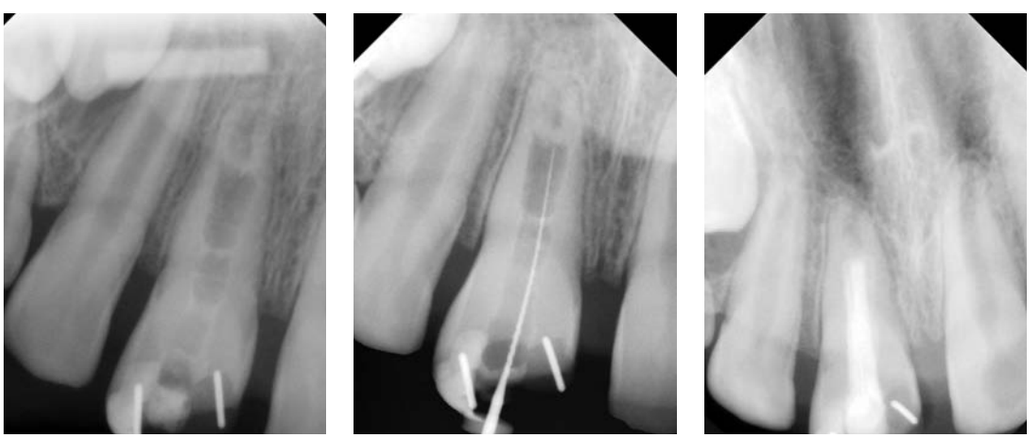


46.7 Apexification (schematic)

Left: Well perfused and vital tissue at the open apex.

Middle: The stimulating effect of calcium hydroxide leads to proliferation of periodontal ligament cells at the apex and the deposition of new cementum.

Right: Creation of a calcific bridge. This bridge may lie at the canal orifice or within the canal itself.



46.8 Apexification (radiographic)

Left: Initial situation. Apical radiolucency following anterior tooth trauma with direct pulp capping of the exposed pulp and an acrylic resin build-up incorporating parapulpal pins.

Middle: Intracanal calcific bridge at 18 months following treatment with calcium-hydroxide dressings.

Right: The conventional root canal filling leads to a suboptimal result in the apical area because of the funnel shape of the canal lumen. In addition, the applied pressure increases the risk of root fracture.

46.9 Apexification (clinical)

Left: Initial situation (same patient as above). Abscess formation and mobility of tooth 11.

Middle: Changing the calcium-hydroxide dressing under rubber dam every 3–6 months. Caution: over-instrumentation may compromise the chances for success!

Right: Clinical situation following completion of treatment. The gingiva is sound, the tooth is stable, the patient is free of discomfort. A slight gray discoloration of the tooth can be discerned.

Alternative Methods

In contrast to conventional apexification methods that use calcium hydroxide, the advantage of using mineral trioxide aggregate (MTA) is that an artificial hard substance barrier is created immediately and the treatment time is significantly shortened. However, because MTA in its set condition exerts no disinfection effect, the treatment of any apically located infections should precede the filling; the canal should be irrigated and an interim calcium-hydroxide dressing placed.

Following closure of the apex using MTA with a minimum thickness of 3 mm, the root canal can be filled with gutta-percha and sealer. This is ideally done using a thermoplastic system and the vertical compaction technique in order to fill the irregular, funnel-shaped canal appropriately.

Subsequently, routine adhesive treatment of the coronal cavity is carried out. Recent studies show that because of the rapid apical closure of a root using MTA, the danger of fracture is clearly diminished in contrast with long-term dressings with calcium hydroxide (Andreason, 2006).

46.10 Apexification with MTA

Left: Radiographic situation following anterior tooth trauma. Extensive apical radiolucency.

Right: Radiograph following conventional healing using calcium-hydroxide dressings for approximately 3 months.

46.11 Comparison of MTA and calcium hydroxide

	MTA	Calcium hydroxide
Cost in time	One to two sittings following primary infection control	Multiple applications over a long period
Mechanism of action	Artificial barrier with subsequent bone apposition	Induction of hard substance formation
Costs	High	Low
Success	(Still) questionable, seems to be good	74%–96%
Clinical procedure	Difficult	Simple
Long-term experience	None to date, studies in progress	Yes, well documented
Breakage resistance	High	Low following long dressing time

46.12 Apexification with MTA

Left: Closure of the apex using MTA. Application directly onto the apex is difficult; note material deposited also on the canal walls. In order to guarantee complete setting of the material, it is recommended that the definitive root canal filling be performed 24 hours later.

Right: Canal filled with gutta-percha, using the vertical compaction technique (System B/Obtura) (courtesy of M. Duggal).

47 Immunopathogenesis of Periradicular Disease

Following root canal invasion, endodontic pathogens and their pathogen-associated molecular patterns (PAMPs) instigate nonspecific (innate) and antigen-specific (acquired) host immune responses within pulpal and subsequently periradicular tissues. Central to the initiation of appropriate innate host responses is the cellular recognition of PAMPs by endodontic pathogen-binding members of the toll-like receptor family (TLRs), which bind PAMPs. This response induces an influx of "innate" immune cells into the periradicular region, which occurs within 3 days after pulp exposure (Kawashima et al., 1996).

Of clinical significance, this inflammatory infiltrate and concomitant bone destruction occurs within the periradicular tissue prior to pulp tissue necrosis (Suzuki et al., 1999). Although host-defensive reactions are activated to prevent further infection, perpetuation of the inflammatory response eventually elicits periradicular disease (PRD).

Epidemiologic studies reveal that PRD is remarkably prevalent, occurring in 33%–80% of adult populations (Tsuneishi et al., 2005); 35%–80% of individuals may have more than one affected tooth (De Moor et al., 2000) and as many as 14 affected teeth (Kabak and Abbott, 2005). PRD is associated with a large proportion of root-filled teeth, from 25% to 64.5% (Loftus et al., 2005), and these teeth are five to 12 times more likely to have radiographic evidence of PRD than teeth without root fillings (Petersson et al., 1986; Buckley and Spångberg, 1995).

Furthermore, teeth with inadequate root fillings are significantly correlated with PRD lesions (Chugal et al., 2003). Importantly, there is clear evidence that the presence of a periradicular lesion prior to the start of treatment is the single most significant factor influencing successful outcome of endodontic therapy (Negishi et al., 2005).

Patient susceptibility to PRD is determined by complex interactions between endodontic microorganisms, host factors, and environmental components. It is now accepted that the host's immune response is an important constituent in the outcome of endodontic treatment, this having been previously largely ignored (Marending et al., 2005).

To be able to clinically attenuate immune responses and successfully eradicate disease, it is essential to have an appreciation of the complex pathologic processes that contribute toward PRD.

The innate cellular immune system is responsible for rapidly initiating cellular responses essential for early microbicidal host defenses. The inflammatory cellular infiltrate consists of neutrophils, macrophages, mast cells, lymphocytes, natural killer cells, plasma cells, and eosinophils.

Cells of the innate immune system	Cells of the acquired immune systems	Cytokines with primarily pro-inflammatory effects	Cytokines with primarily inhibitory effects	Cytokines of the acquired immune system
Dendritic cells	Dendritic cells	Type 1 interferon (IFN)		CD4⁺-T-helper (T_H)1 response: IL-2, IFN-γ
Antigen-presenting cells (APCs)	APCs	Granulocyte macrophage-colony stimulating factor (GM-CSF)	Transforming growth factor (TGF)-β	CD4⁺- T_H2 response: IL-4, IL-5
Eosinophilic granulocytes	B cells	Tumor necrosis factor (TNF)-α		
Neutrophilic granulocytes	CD4⁺ cells	IFN-γ		
Macrophages	CD8⁺ cells	Interleukin (IL)-1, IL-12, IL-15, IL-17A, IL-18		
Natural killer (NK) cells				
T-NK precursor cells				
γ β T-cells (epithelial)				

47.1 Cytokines as communication mediators

Cytokines establish the communication between the cells of the innate and the acquired immune defense systems. They possess inflammation-enhancing and sometimes also inflammation-inhibiting functions.

The activity on the CD4⁺ receptors of T-helper cells of subtypes T_H1 and T_H2 lead to successful control of the pathogens or to repeated (chronic) disease.

Innate and subsequent adaptive immune responses are not isolated sequential host events in the response to infection but are interlinked through cellular contacts and secretion of soluble inflammatory mediators.

Among the bacterial-derived moieties, lipopolysaccharide (LPS) from Gram-negative bacteria plays a key role in pulpal disease (Khabbaz et al., 2001) and subsequently PRD (Nelson-Filho et al., 2002). LPS induces periradicular bone destruction (Mattison et al., 1987) and its concentration within the root canals correlates with the presence of periradicular lesions (Horiba et al., 1991).

Nevertheless, cell wall components from Gram-positive bacteria and other virulence factors, including fimbriae and lipoprotein, likely contribute toward PRD development (Wang and Stashenko, 1993).

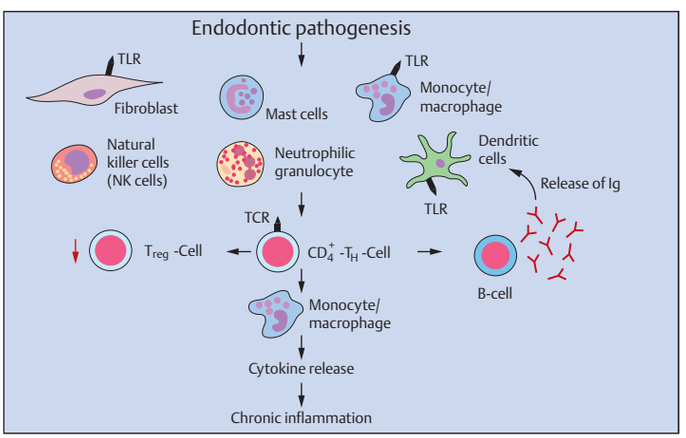
Adverse effects of endodontic pathogens may not be because of direct actions on bone-derived cells. More importantly, bacteria-derived moieties indirectly stimulate bone resorption by inducing a myriad of inflammatory mediators involved in the recruitment and maturation of osteoclasts, including cytokine expression.

Cytokines are a diverse group of small, secreted proteins acting as communication molecules between host cells, orchestrating and modulating the host immune-inflammatory responses to endodontic pathogens. Although immune cells are the primary source of these inflammatory mediators, stromal cells within the PRD lesion, such as epithelial cells, endothelial cells, and fibroblasts, are also important sources. Cytokines released at sites of infection have the capacity to modify normal bone remodeling processes. Macrophage and T-cell–derived proinflammatory cytokines IL-1α, IL-1β, TNF-α, and IFN-γ are recognized as mediators of tissue destruction at the initiation and during subsequent progression of PRD (Kawashima and Stashenko, 1999). This provokes a cascade that amplifies or suppresses inflammation by inducing further release of cytokines and growth factors. IL-1 is significantly upregulated at the onset of pulpal and periapical inflammation (Tani-Iishii et al., 1995) and results in the activation and recruitment of osteoclasts and destruction of surrounding periradicular bone (Dewhirst et al., 1985).

Although the above-mentioned inflammatory events are essential for host defence against a bacterial challenge, excessive and prolonged responses are damaging to the adjacent periradicular tissue.

47.2 Inflammatory cells in periradicular disease

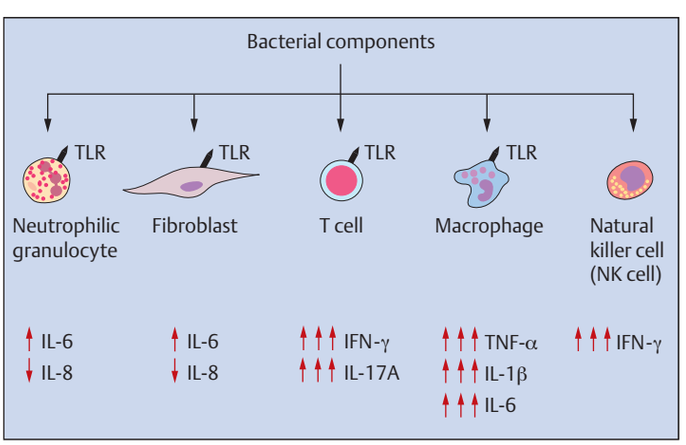
Endodontic pathogens stimulate available immune and stromal cells via TLR receptors. The subsequent activation of the acquired immune system enhances the release of proinflammatory mediators. The feedback from the cells involved in the inflammatory process causes the chronic form of the disease.

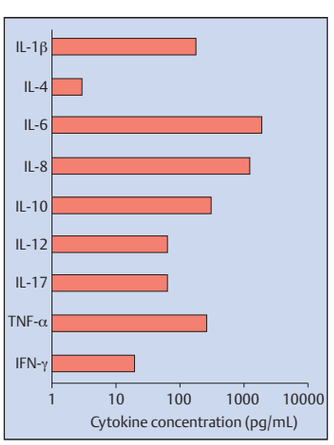


47.3 Inflammatory cytokine regulation

For defense against bacteria, in the periradicular region, the production of characteristic proinflammatory cytokines is induced. The simultaneous secretion of IL-10 works against this function. Tissue destruction is therefore impeded.

Right: A high expression of IFN-γ, TNF-α, and IL-12 during periradicular disease implies the dominance of CD4+-activated T_H1 pathway. Failed expression of cytokines in T_H2 cells leads to improper regulation of the inflammatory processes.



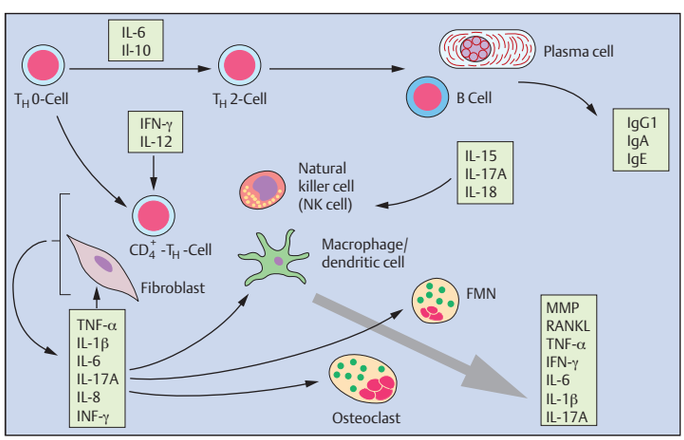


Healthy adult alveolar bone is a specialized dynamic connective tissue that undergoes continuous remodeling. Physical factors such as mechanical stimulation and polypeptides, including cytokines and hormones, are responsible for controlling the equilibrium between osteoblastic and osteoclastic activities. Indeed, osteoclastic activity and bone metabolism are primarily modulated through the key bone mediator receptor activator of nuclear factor-κB ligand (RANKL), which in turn is regulated by secretion of its antagonist osteoprotegerin (OPG) (O'Brien et al., 2000).

Subsequent to the initiation of PRD, bone destruction is controlled by the numerous cell protagonists within the lesion that interface with the bone tissue, immune system, and vascular components of the PRD tissue. Thus, monocytes, macrophages, lymphocytes, and endothelial cells are also implicated in bone remodeling by direct contact with bone cells.

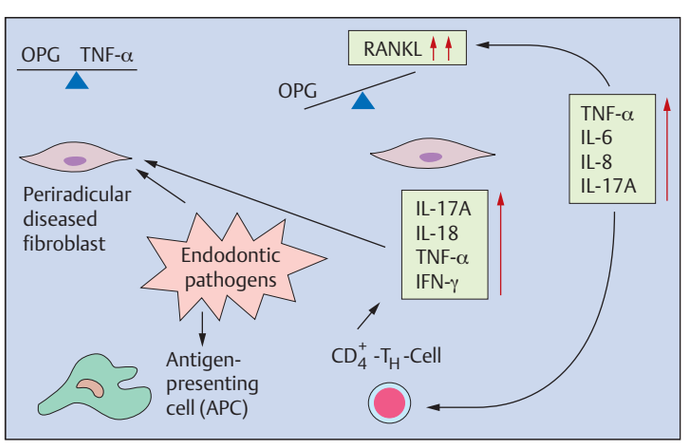
Through actions on stromal osteoblastic cells, IL-1β and TNF-α increase local concentrations of RANKL. However, potentially destructive pathways arising from concomitant release of IL-1β and TNF-α are moderated by a simultaneous increase in OPG production from stromal osteoblasts (Hofbauer et al., 1999). IL-1, TNF-α, IL-15, and IL-17A contribute to bone destruction by enhancing osteoclast formation and stimulating production of RANKL from bone-lining cells (Dai et al., 2004).

The successful identification of therapeutic targets that disable destructive immuno–inflammatory pathways within PRD is highly desired. To achieve this, it is essential to have a functional understanding of the complex interactions among the different cell populations, between these cells and the tissue matrix, and between cells of the PRD lesion and cells within the matrix of the surrounding dentoalveolar bone. Through this knowledge, the quantification of inflammatory mediators by root canal sampling may elicit information for the clinician of lesion status and assist in defining treatment prognosis. Thereby, root canal exudates could be effectively sampled and clinicians informed as to whether canals can be successfully obturated, and treatment therefore terminated. Importantly, this may aid the clinician in advising the patient as to the predicted outcome of the treatment procedure (Spangberg, 2000).



47.4 Mediators of the destructive immune response

Inflamed periradicular lesions constantly secrete a certain amount of proinflammatory cytokines. This effectively enhances the immune response, so that the subsequent cellular activation leads to destruction of the surrounding alveolar bone.



47.5 Regulation of bone destruction

The release of matrix metalloproteinases (MMPs), RANKL, TNF-α, IL-1β, IL-6, IL-8, and IL-17A by fibroblasts and inflammatory cellular components during the periradicular lesion leads to activation of cells in the bone matrix, including the osteoclasts. A lack of sufficient inducible OPG shifts the balance between bone deposition and bone resorption.

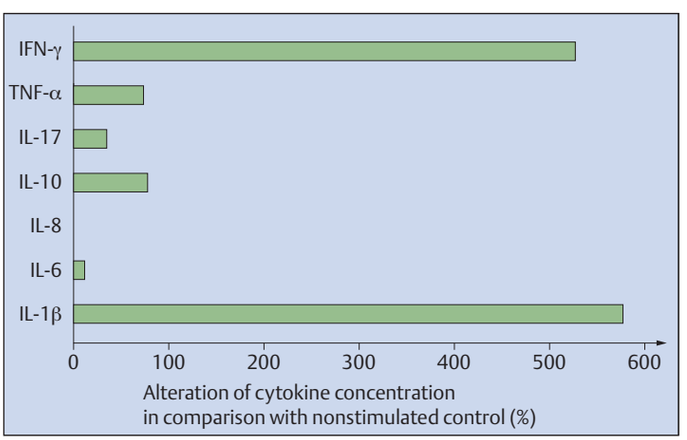
Studies using the rodent pulp model have demonstrated that IL-1α, IL-1β, and TNF-α expression are upregulated within PRD tissue cells at an early stage of infection and bone resorption (Bletsa et al., 2004). Their expression within the PRD lesion contributes toward the synthesis of downstream inflammatory mediators such as IL-6 and IL-8. These proinflammatory molecules also act on fibroblasts, thereby stimulating the production of matrix metalloproteinases, which elicit degradation of extracellular matrix components.

Of clinical relevance, high concentrations of IL-1β (Kuo et al., 1998), TNF-α (Safavi and Rossomando, 1991), IL-6 (Takeichi et al., 1998), and IL-8 (Shimauchi et al., 2001) have also been detected within root canals of teeth exhibiting PRD. Interestingly, a trend toward raised IL-1β, IL-6, and IL-8 concentrations has been demonstrated in symptomatic teeth (Lim et al., 1994; Shimauchi et al., 2001; Radics et al., 2003). These data reinforce that cytokines are central in orchestrating events that culminate in chronic PRD and that cytokine expression from root canal sampling relates to clinical findings.

In addition to sampling of root canal exudates, identification of novel inflammatory mediators and their contribution to proinflammatory pathways would allow the development of therapeutic devices that could be placed within the root canal or inserted directly into the PRD lesion. Thereby, destructive inflammatory responses may be blocked and tissue repair promoted. Therapeutic blockade of upstream proinflammatory cytokines within the lesion may therefore be advantageous, this approach having been successfully used in chronic inflammatory diseases including the targeting of TNF-α in rheumatic diseases (Taylor, 2003).

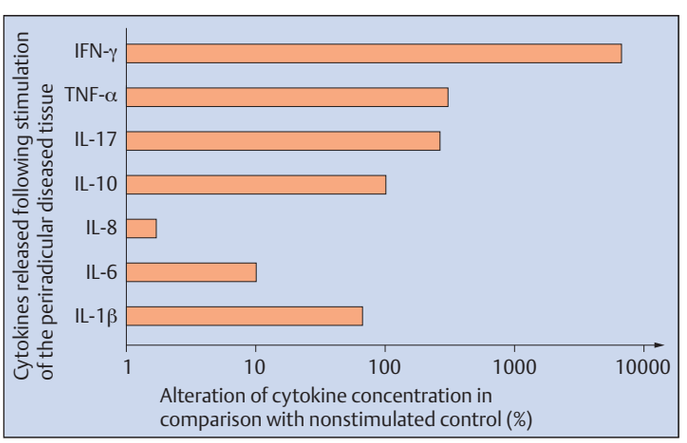
47.6 Influence of Gram-negative bacteria

The effects of components from Gram-negative bacteria on tissue cultures of periradicular processes lead to the production of various proinflammatory cytokines. The significant release of IL-1β, TNF-α, and IFN-γ is probably associated with the tissue destruction in the periradicular region.



47.7 Influence of Gram-positive bacteria

The addition of components from Gram-negative bacteria onto tissue cultures from periradicular disease induces an enormous increase of cytokine concentration, which precedes a proinflammatory response.



48 Endodontology and General Systemic Health

The "Focal Infection" Era

Clinicians should have a sound understanding of the potential effects of endodontic diseases and their treatment on the systemic health of their patients, and an awareness of previous clinical studies. Miller originally implicated microorganisms in root canal infections in the early 1890s. However, it was not until Hunter (1900) theorized that oral-derived bacteria could disseminate throughout the body, thereby inducing disease, that the medical profession took significant interest in infections of the dental pulp and oral tissues. From 1910 to the 1940s, numerous studies reported the adverse effects that diseased tissue sites, particularly infected oral tissues, had on the host (Murray and Saunders, 2000). Billings et al. (1912), Mayo (1914), and Rosenow (1917) were instrumental in establishing acceptance within the medical profession that localized low-grade chronic infections were capable of inducing disease elsewhere in the body. These early studies established the "focal infection theory," introducing the concept that systemic dissemination of microorganisms and associated toxins from a focus of circumscribed infection established or exacerbated systemic disease (Hunter, 1921). Indeed, Rosenow proposed that enclosed lesions capable of draining only into the circulation, such as infected root canals, were the most dangerous foci of infection.

The focal infection theory was fiercely debated, with root canal infections or infections of the surrounding periodontal attachment apparatus implicated as culprits in numerous diseases (Holman, 1928). Consequently, evidence from clinical research recommended wholesale dental extractions and tonsillectomies as the panacea for several systemic ailments. Rhoads and Dick (1932) purported all pulpless teeth as likely foci of infection, advising dental extractions as prerequisite in medically compromised patients to improve their health and well-being. Moreover, Rhein et al. (1926) even advocated extraction of healthy teeth for the prevention of focal infection! In the United States, opposition to root canal treatment (RCT) became so powerful that the majority of institutions ceased clinical endodontic teaching in favor of dental extractions (Grossman, 1971). As a result, progress in RCT procedures, still very much in their infancy, was curtailed for over 40 years.

However, by the 1930s the research community began to raise doubts about the quality of evidence endorsing the focal infection theory (Bernhardt and Hench, 1931). Indeed, Cecil and Angevine (1938) disputed the validity of results from previous work (Cecil and Archer, 1927), which had recommended prompt removal of infectious dental foci at an early stage to cure rheumatoid arthritis (RA). Furthermore, it proved difficult to reproduce results from earlier studies that had implicated *Streptococcus sp*-induced RA (Dawson et al., 1932). Reimann and Havens (1940) suggested that Hunter's views, expressed 30 years previously, had been misinterpreted, concluding "the removal of local infections in the hope of influencing remote or general symptoms and disease must still be regarded as an experimental procedure not devoid of hazard." Although a minority continued to uphold the general concept of focal infection (Ensign, 1945), it became accepted that a more logical and scientific approach to focal infection had to be adopted. In a critical review appraising the relationship between focal infection and rheumatoid disease, Freyberg (1946) postulated that removal of foci of infection should only be considered as part of a broad spectrum of treatment. Agreement was reached that removal of infected foci would be of little benefit in chronic diseases.

Importantly, researchers and clinicians began to acknowledge that not every "focus of infection" was responsible for a "focal infection" and that anemia, emotional strain, exposure, malnutrition, endocrine imbalance, fatigue, senility, trauma, age, and infectious disease all contributed to lowering patients' resistance to disease (Arnett and Ennis, 1933; Shuster, 1941). Those refuting the focal infection theory claimed that generally no foci of infection could be located within afflicted individuals enrolled in the research studies (Easlick, 1951). Furthermore, following removal of infected foci, no discernible improvements were observed in the patients' medical conditions. Indeed, Mitchell and Helman (1953) ascertained that perfectly healthy individuals had as many septic foci as those with diseases such as arthritis. Critically, early focal infection research was crude, with an absence of control cohorts and reliance on flawed bacteriologic culture techniques that biased findings. These substantial methodologic flaws led to the demise of the focal infection theory.

However, the focal infection theory has resurfaced in modern times, with publication of review papers (Hughes, 1994; Newman, 1996) and a popular book (Meinig, 1986), which contests that the dental profession has chosen to ignore a significantly researched concept related to the general health of the population. Once again, the role of RCT and its impact on long-term general health has been questioned. Nevertheless, the potential association between systemic health and RCT has been strongly disputed by dental governing bodies and there remains little evidence to substantiate the claims (Murray and Saunders, 2000).

Modern Endodontology, Oral Disease, and Systemic Health

Following the concept of focal infection, considerable research activity has attempted to analyze the relationship of oral diseases, in particular periodontal disease (reviewed in Dietrich and Garcia, 2005), with general systemic disease. In contrast, investigations detailing the relationship of PRD or root canal therapy to systemic health have been limited. However, antigen delivery through the root canals of primates and rabbits has been shown to induce both local and systemic immunologic responses (Barnes and Langeland, 1966; Okada et al., 1967). Further, animal studies have demonstrated that antigenic stimulation within the root canal elicits a strong immune response and production of circulating antibodies (Steffen et al., 1976; Dahlen et al., 1982). Levels of systemic inflammatory markers, such as C-reactive protein, have been demonstrated at increased levels in humans with PRD and these are reduced following endodontic treatment (Márton et al., 1988; Márton and Kiss, 1992). However, recent animal experiments contradict these findings (Buttke et al., 2005). Whether chronic latent PRD is capable of long-term stimulation of circulating antibodies or inflammatory molecules and whether these have any adverse effects on the systemic health of the host requires further elucidation.

The development of more sophisticated molecular biologic techniques to identify microorganisms and investigate their complex interrelationships has reinvigorated interest in oral microbiology (Spratt, 2004). Using such highly sensitive microbiologic procedures, Debelian et al. (1997, 1998) proposed that microorganisms present in bacteremia following RCT originate from the root canal. These modern laboratory methods will enable researchers to identify whether microorganisms implicated in the etiology of septic arthritis and other systemic diseases genetically match those derived from an endodontic source (Payne and Wolfe, 1994).

Despite the demise of the focal infection theory, publications continue to link dental foci of infection with RA (Shimizu et al., 1977). However, others suggest that no relationship exists between chronic PRD and RA (Sugita, 1994), although controlled scientific evidence to support this claim is lacking. Newman (1996), in reviewing the theory of focal infection, suggested a possible link between systemic disease and RA with oral disease. In a series of experiments, Malmstrom et al. (1975) analyzed the significance of periradicular lesions in individuals with RA. The link between rheumatoid disease and presence of periradicular lesions was found to be tenuous but some important observations were made. The authors noted a positive correlation for the presence of IgG rheumatoid factor in the periapical tissues of rheumatoid patients. The most convincing association was that of the underlying immunologic and inflammatory histologic reactions, which appeared to be similar within both PRD and RA lesions (Malmstrom and Natvig, 1975).

Nevertheless, several more recent case studies cite odontogenic infection as the initiator of serious systemic complications including orbital infections (Blake et al., 2006), intracranial abscesses (Saal et al., 1988), cerebral infarction (Syrjanen et al., 1989), bacteriospermia and subfertility (Bieniek and Riedel, 1993), necrotizing fasciitis (Fenton et al., 2004), mediastinitis (Papa and Jones, 2005), periorbital cellulitis (Ramey and Lockey, 2006), deep neck infections (Huang et al., 2004), and toxic shock syndrome (Navazesh et al., 1994). Although rare, spreading odontogenic infections may also result in mortality (Bulut et al., 2004) and these may even occur within healthy individuals (Green et al., 2001). Not only do untreated root canal infections have the potential to cause serious although infrequent health problems (Riggio et al., 2006), but septicemia (Lee, 1984) and orbital infections (Koch et al., 2006) have also been reported as complications arising from RCT.

While this chapter focuses on the association between root canal infections and PRD and systemic health, the clinician must be also be aware of possible *local* complications. Indeed, untreated root canal infections may incite local pathology such as inferior alveolar nerve paresthesia (Giulliani et al., 2001). In addition, inappropriate RCT procedures may induce localized adverse effects including nerve paresthesia (Morse, 1997), anaphylaxis (Candura, 1991), alveolar bone necrosis (Ozmeric, 2002), and allergic reactions (Scully et al., 2003). An understanding of the endodontic materials being utilized is a prerequisite because some have the potential to exert mutagenic or genotoxic effects on the host tissues (Geurtsen and Leyhausen, 1997).

Recent research methodology has taken into account the many deficiencies in older, traditional studies. Therefore, not only has the primary factor in a disease process been analyzed, but, additionally, the interrelationship of other risks and confounding factors (Caplan, 2004). The dental profession is currently more closely scrutinizing the association between dental disease and systemic disorders. Although chronic periodontal disease may be recognized as a potential risk factor for cardiovascular disease (CVD) (Matilla et al., 2005) and adverse pregnancy outcomes (McGaw et al., 2002), currently there is insufficient evidence to provide support for causality (Scannapieco et al., 2003).

The relationship between PRD and CVD is less well researched and remains unclear (Frisk et al., 2003). Nevertheless, PRD has been implicated as a risk indicator for mortality in CVD patients (Jansson et al., 2002).

Odontogenic infection has also been implicated as a source for pyrexia of unknown origin (PUO) (Hedstrom et al., 1980; Siminoski, 1993). Some authors have indicated the prevalence of PUO of oral etiology to be as high as 14% (Naschitz and Yeshurun, 1985), which has led to further debate about the possible involvement of root canal infections in such cases (Gordon et al., 1988). Bacterial products within the root canal (Shinoda et al., 1987) are postulated as likely initiating factors in several PUO cases. These case series further raise the possibility of a link between root canal infections and general systemic illness (van Velzen et al., 1984; Meurman 1997).

Bacteremia in Endodontics

Subsequent to the demise of the focal infection theory, the research focus shifted toward investigating potential adverse systemic effects of bacteremia arising from oral and medical procedures. Therefore, dental research started to analyze the only apparent identifiable form of a focal infection arising from dental origin, that of infective endocarditis (Jones and Newsom, 1931). Importantly, the association between oral focal infection and infective endocarditis was seen to arise after acute episodes of infection with no chronic oral infection identifiable as initiating or aggravating systemic illness.

Early studies investigating microbial species within bacteremia originating from foci of infection used rudimentary laboratory equipment and techniques, capable of cultivating only limited numbers of microorganisms (Richards, 1932). Nevertheless, these studies established that bacteremia was possible from foci of infections within a variety of tissue sites, including the oral cavity. Although bacteremia occurred after dental extractions (Burket and Burn, 1937), others suggested that apical infections were "effectively walled off by the associated inflammatory reaction" and thus did not contribute toward a bacteremia (Elliot, 1939).

The relationship between bacteremia and endodontic procedures was subsequently investigated (Beechen et al., 1956; Bender et al., 1960). Indeed, Kennedy et al. (1957) established that the introduction of *Streptococcus haemolyticus* into the root canal induced bacteremia. Not only was dental extraction-induced bacteremia implicated in bacterial endocarditis but "noninvasive" procedures such as periodontal scaling and RCT were cited as causes of fatal bacteremia (Eisenbud, 1962).

With the understanding that a bacteremia could occur during root canal preparation (Ross and Rogers, 1943), the extent of bacteremia after RCT was measured (Klotz et al., 1965). These studies illustrated that bacteremia was more likely to occur if the RCT was carried out beyond the root apex rather than maintained within the confines of the root canal system. However, postoperative bacteremia from endodontic procedures was demonstrated to persist for less than 10 minutes (Bender et al., 1960). It remained until 1976 for a study to utilize aseptic and improved anaerobic culture techniques to measure bacteremia subsequent to surgical and nonsurgical RCT (Baumgartner et al., 1976). The authors reiterated that a bacteremia was not induced when instrumentation remained within the root canal system. Furthermore, Baumgartner et al. (1977) demonstrated that nonsurgical RCT produced a lower incidence of bacteremia than surgical flap reflection, periradicular curettage or tooth extraction.

More recent investigations of root canal treatment–induced bacteremia using contemporary anaerobic techniques and more sophisticated diagnostic equipment provide further evidence that bacteremia is induced if root canal instrumentation is carried beyond the apex (Debelian et al., 1992). Importantly, Debelian et al. (1995, 1996) and others (Savarrio et al., 2005) demonstrated that bacteremia occurs even if instrumentation is *maintained* within the root canal. These studies demonstrate more frequent bacteremia arising from RCT procedures than previously described. This is probably attributable to the use of more sensitive culturing and identification methods. However, as only minimal bacterial quantities are detected within the blood and with the knowledge that bacteremia occurs during regular oral hygiene measures and mastication (Forner et al., 2006), the systemic significance of bacteremia arising from RCTs remains to be determined.

Effects of General Systemic Health on Endodontics

The possibility of systemic disorders arising from oral foci of infection appears particularly likely in susceptible individuals with compromised immune responses. These include cirrhotic patients (Borowsky et al., 1979), patients regularly exposed to steroids (Latronica and Shukes, 1973), the elderly (Navazesh and Mulligan, 1995), asplenic patients (Kragsbjerg and Rydman, 2001), and RA patients (Stoll et al., 1996). Through such reports, interest in the focal infection theory has again resurfaced. Nevertheless, due to the lack of carefully controlled studies, one may only speculate that an endodontic focus of infection was the origin of the implicated microorganisms and the cause of chronic systemic illness.

Conversely, few studies have investigated the effects of systemic disease on the success and outcomes of root canal procedures. A retrospective study has suggested that human immunodeficiency virus (HIV) infection has no adverse effect on healing of PRD lesions following RCT (Quensell et al., 2005). In contrast, diabetic patients appear to have an increased predisposition to the development of PRD (Falk et al., 1989). This is particularly aggravated by poor glycemic control, which leads to increased susceptibility to spreading odontogenic infections (Huang et al., 2005). Furthermore, RCT success is delayed and reduced in patients with diabetes who have existing PRD compared with healthy cohorts. This may be a consequence of reduced host immune response to bacterial infections (Iwama et al., 2006). Recent evidence also identifies a dose–response relationship between cigarette smoking and the risks associated with RCT (Krall et al., 2006). Essentially, it is gradually being recognized that the host's immune response is an important factor in the outcome of endodontic treatment procedures, this having previously been largely ignored (Marending et al., 2005).

No modern investigations provide evidence definitively establishing that RCT has any adverse systemic effects since Rogers (1976) and Ehrmann (1977) dismissed any relationship between endodontics and focal infection.

With the increasing public awareness of health and health maintenance, the possibility that disease within the periradicular tissues could perhaps elicit or exacerbate systemic disorders demands definitive clarification as to whether or not there exist any real cause-and-effect relationship(s) between endodontic treatment and general systemic health.

49 Single Versus Multiple Sitting Root Canal Treatment

Single sitting root canal treatment involves complete canal system preparation, irrigation, and obturation in one treatment session. It also involves removal of existing previous root filling material at the same sitting if carrying out a nonsurgical retreatment procedure. It is generally accepted that in teeth with a vital pulp, in which there is only superficial infection of the coronal pulp, immediate obturation following pulpectomy and canal instrumentation is the most appropriate treatment.

The long-running debate over whether to treat the tooth in one or more sittings involves cases in which there is a necrotic pulp and evidence of apical periodontitis, indicated by an area of radiolucency on a periapical radiograph. There are two schools of thought:

- The first assumes that all microbes and their byproducts are eliminated during the shaping and cleansing procedures, or that residual bacteria are entombed within the canal by a well-fitting root filling placed at the same sitting.
- The alternative view is that some bacteria almost always remain after instrumentation, and therefore an intracanal medicament should be placed *between* sittings to eliminate any residual flora. The canal system is reirrigated and then filled at the second sitting.

The principle for the latter approach is based on a study by Sjögren et al. (1991), wherein bacterial sampling and culturing were carried out following complete preparation of single-rooted teeth. Reduced numbers of bacteria were identified in more than half the samples – a finding that has been confirmed in numerous subsequent studies. Following placement of a calcium hydroxide dressing in the canal systems for 7 days, an additional bacterial assay was done, and no persisting viable bacteria could be detected. The authors concluded that a calcium hydroxide dressing for at least 7 days was necessary to eliminate all viable bacteria from the root canal.

Literature Review

The two criteria studied following both single and multiple sitting approaches have been the incidence and severity of postoperative pain and the longer-term outcome of the procedure.

There appears to be no significant difference in the amount of posttreatment pain, according to the many publications on the subject (Fox et al., 1970; Mulhearn, 1982; Roane et al., 1983; Oliet, 1983; Genet et al., 1986; Fava, 1989; Trope, 1991; DiRenzo et al., 2002; Yoldas et al., 2004). Similarly, no significant differences in healing rates were reported in a number of admittedly limited and relatively short-term studies until a landmark publication by Sjögren et al. (1997). Fifty-five single-rooted teeth with evidence of apical periodontitis were thoroughly cleansed and shaped before bacterial sampling, and bacteria were still detected in 22 cases. All teeth were nevertheless obturated and then reviewed 5 years later. Complete healing had occurred in 94% of cases that had yielded an initial negative culture, but in just 68% in which samples were positive before root filling. The difference was statistically significant. The authors' conclusions emphasized the importance of eliminating bacteria from the root canal system before obturation. They stated that this objective could not be achieved reliably without a medicated intracanal dressing.

Sjögren et al. carried out a well-controlled study, but included only a limited number of single-rooted teeth. However, two failures occurred in the negative culture group. Surgery was carried out in one case; bacteria were identified subsequently in a lateral canal and within the periapical lesion. Thus, even their advanced anaerobic culturing technique may still not have located bacteria in lateral canals and apical ramifications and therefore the findings, as in any single study, should be viewed with a degree of caution.

Since then, only three other significant comparative studies have been published. Trope et al. (1999) evaluated radiographic healing of just over 100 single canals one year after treatment. The canals were divided into three groups – single sitting, two sittings with no medicament, and two sittings with calcium-hydroxide dressing for at least 1 week. The two-sitting approach with no intra-canal medicament clearly exhibited the poorest rate of healing. There was no significant difference between the single-sitting group and two-sitting group with calcium hydroxide dressing. However, the authors had to reduce their sample size to only 41 teeth to equalize the initial baseline to comparable degrees of apical periodontitis. They found an improved rate of healing with the two-sitting plus calcium hydroxide group, but the difference was not significant.

Weiger et al. (2000) carried out a prospective study comparing prognosis after single and two-sitting plus calcium hydroxide treatment in 76 patients, including a number of multi-rooted teeth. They found no significant difference in the likelihood of healing between the two groups. As with the other publications, the study is open to criticism because there were more molars in the two-sitting group and more so because the calcium hydroxide had been placed with paper points. These may have absorbed a considerable amount of the water-based carrier material and thus reduced the effectiveness of the medicament.

Peters and Wesselink (2002) assessed the healing of 42 single canals, divided into two equal groups of single sitting and the two-sitting protocol with calcium hydroxide for 4 weeks, up to 5 years following treatment. Once again, no significant difference in overall healing rates could be discerned. This study was unusual in that bacterial sampling and culturing of the two-sitting group after the calcium hydroxide had been in situ for 4 weeks indicated an increase in the numbers of residual bacteria. There may have been a problem with the method of calcium hydroxide placement and perhaps some coronal leakage between sittings; also, the numbers were too small for any definitive (statistical) conclusions.

The combined results were examined in a systematic review (Sathom et al., 2005), which confirmed that, with the limited information available, there was no significant difference between the two endodontic treatment protocols.

With regard to the effectiveness of calcium hydroxide as an intracanal medicament, a review by Siqueira and Lopes (1999) queried whether the material was as effective as originally reported by Sjögren et al. (1991). Very recently Sathom et al. (2007) carried out a systematic review of the available data and concluded that calcium hydroxide has limited effectiveness in eliminating bacteria from the human root canal, as assessed by in vitro culture techniques.

Currently, the literature provides no clear indication as to whether one treatment regimen leads to a significantly better outcome. This is an area where more extensive, well-controlled, prospective, comparative outcome studies are urgently needed.

The Single-sitting Approach

If there is no guidance from the literature, the decision concerning whether to perform treatment in a single sitting comes down to individual clinician preference and dogma. The primary advantages of the single-sitting protocol are:

- familiarity with anatomy, canal shape, contour, and size facilitates obturation;
- no residual medicament to affect sealer flow or interact/react with dentin;
- no risk of microbial contamination beyond the temporary coronal seal between sittings;
- significant reduction of clinical time;
- patient convenience – no additional appointment required.

However, there are some disadvantages to this approach as well, for example:

- no easy access to the apical portion of the canal if there is a subsequent “flare-up”;
- no opportunity to reevaluate possible additional canal locations or the effectiveness of preparation by resolution of symptoms;
- no opportunity for an intracanal medicament;
- increased appointment time with attendant patient fatigue and reduced cooperation;
- operator fatigue due to the longer period of intense concentration;
- less flexible scheduling of appointments (if a patient fails to appear for her/his appointment, more time is lost in the practice environment);
- difficulty in assessing overall time required for nonsurgical retreatment procedures.

In the end, decision about the treatment approach may depend on the clinician’s clinical experience and interpretation of the literature, a preference for longer appointments, the ease and speed of preparation, and thus adequate time for effective irrigant action before obturation. It may prove difficult to adhere to the practice time scheduling if treatment must be completed at one sitting, especially when nonsurgical retreatment is undertaken. Some clinicians and patients prefer shorter appointments; while others would much rather complete the procedure in just a single sitting.

However, it is not appropriate to obturate a canal system if there is frank drainage of pus or exudate following the obturation phase; if the canals cannot be dried, they should be dressed with calcium hydroxide and the patient given another appointment. In addition, if there is any doubt about the completeness of the obturation and preparation, or about the location of all canals, the wise and prudent clinician will place an interim medicinal dressing and then complete treatment at a second sitting.

50 Outcomes of Endodontic Treatment

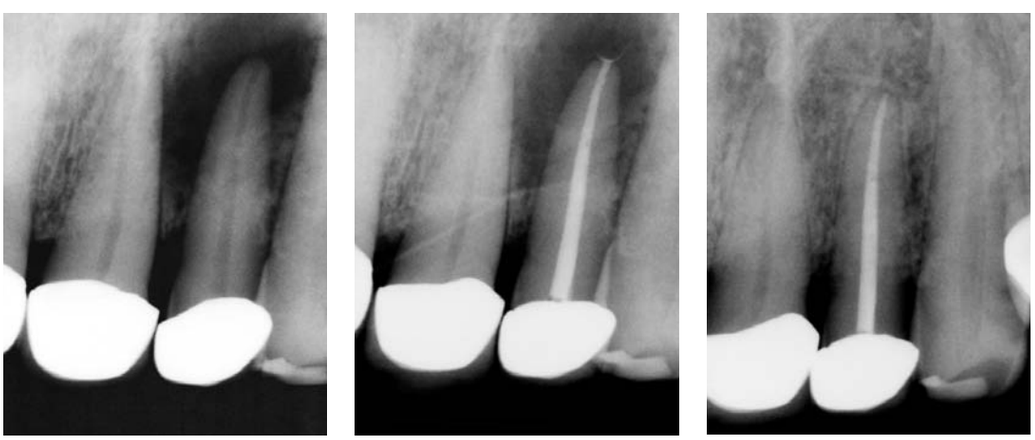
A patient will assess the success of an endodontic procedure by the resolution of any pain or swelling, but the clinician needs a more objective set of criteria to establish success. Strindberg (1956) published the first of the "modern" studies on the outcome of treatment, and he stated the necessary criteria to be:

- absence of pain or swelling;
- no loss of function;
- absence or resolution of a fistulous tract;
- resolution of an area of radiolucency associated with the treated tooth, based on examination of the radiograph.

These criteria are still used today, although to complete resolution of an area of radiolucency, partial resolution or "incomplete healing" is commonly added.

Failure is obviously the absence of some or all of these criteria, although Friedman (2002) has recently argued that the terms "healed" and "failure to heal," or "persistence of disease," are more accurate.

Numerous studies have been published since Strindberg's on the outcome of endodontic treatment, although the majority would today be considered to have fairly low levels of evidence. There are many factors that influenced these studies, for example: the sample size; whether the work was carried out by a single operator or a number of operators; the observation period; the follow-up interval; whether the observers were distinct from the clinicians and whether they had been trained and their degree of interexaminer agreement appraised; the lighting conditions for viewing radiographs; the reexamination of a proportion of the radiographs for consistency of reporting; the strictness of the criteria themselves (i.e., did success or healing mean only complete resolution of areas of radiolucency, or did it include partial resolution as well); and finally, was the study prospective in design or retrospective?

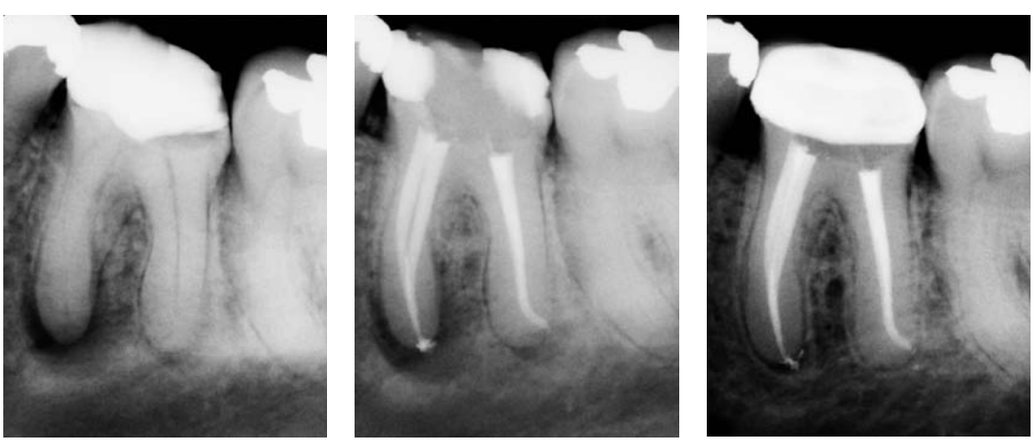


50.1 Primary endodontic therapy I

Left: Tooth 22 exhibits an extensive apical radiolucency.

Middle: Completed root canal filling.

Right: Follow-up radiograph 1 year later. Complete healing, with regeneration of a normal periodontal ligament space.



50.2 Primary endodontic therapy II

Left: Extensive lesion in the region of the mesial root of tooth 36.

Middle: Completed root canal filling.

Right: Follow-up radiograph 1 year later. Significant, but yet incomplete healing. The periodontal ligament space appears to be widened. The tooth was symptom-free.

As a result, only a minority of outcome studies are able to satisfy sufficient criteria to provide reliable evidence of healing (Friedman, 2002). Some examples of these are detailed below. The authors of these papers have either been individual specialist endodontists or students operating under close specialist supervision.

Over the past decade or more, there have been many cross-sectional studies examining full mouth periapical or panoramic radiographs to assess the presence of apical periodontitis in untreated teeth and those that have received root canal therapy. Although the papers derive from many different countries, the results have been surprisingly similar and reveal a much higher percentage of affected areas associated with root filled teeth, with an overall mean in the region of 35%.

It is apparent that the rate of healing for treatment carried out in general dental practice throughout the world is significantly lower than when treatment is provided by specialists or students, undergraduate and postgraduate, when under close supervision. One can presume that most, if not all, of the latter treatment was carried out under rubber dam, whereas it is generally accepted that this simple device is used by a lower proportion of general dental practitioners.

In addition to the standard of care provided, the other significant factors influencing healing, reported consistently in some of the studies in Fig. 50.3, are the presence of an existing area of radiolucency on the preoperative radiograph and the size of that area.

Generally, these studies have not considered the long-term survival of the tooth in question, merely whether healing has occurred. Lazarski et al. (2001), Salehrabi and Rotstein (2004), and Chen et al. (2007) have all published epidemiologic studies with substantial follow-up times (5–8 years). They found very high tooth retention rates of between 93% and 97% when they examined insurance company databases of extremely large numbers of patients (in two of the papers the patient numbers exceeded 1.5 million) who received root canal therapy, regardless of whether the treatment was carried out by generalists or specialists.

Although these publications only reported the data insurance companies were supplied by patients' clinicians, and thus are not well controlled, the sheer size of the samples involved indicate that these figures are very encouraging. Although there is no cause for complacency, and the overall standard of endodontic therapy still needs to be improved considerably, it appears that the survival rate for endodontically treated teeth is considerably higher than the healing rates for apical periodontitis (AP).

50.3 Studies reporting the success of primary endodontic treatment

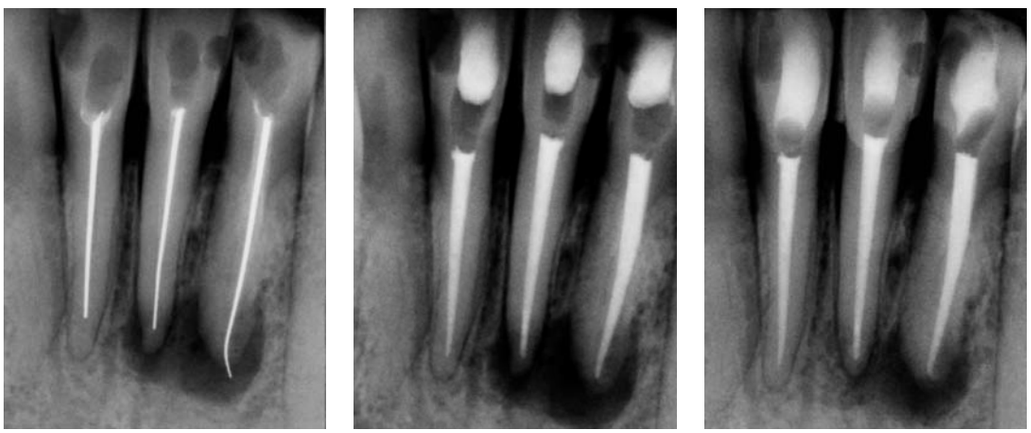
Author(s)	Number of teeth	Follow-up (years)	Complete healing (%)	Incomplete healing (%)
Strindberg 1956	60	0.5–10	80	
Engström et al. 1964	147	4–5	73	
Adenubi and Rule 1976	271	0.5–7	82	8
Kerekes and Trondstad 1979	172	3–5	90	
Byström et al. 1987	79	2–5	85	9
Eriksen et al. 1988	121	3	82	9
Sjögren et al. 1991	204	8–10	86	
Ørstavik 1996	126	4	75	13
Friedman et al. 1995	113	0.5–1.5	63	28
Caliskan and Sen 1996	172	2–5	81	8
Sjögren et al. 1997	53	5	83	
Trope et al. 1999	76	1	80	
Weiger et al. 2000	67	1–5	78	16
Abitbol 2001	72	4–6	74	4
Hoskinson et al. 2002	200	5	78	14
Peters and Weselink 2002	38	1–4.5	76	21

Nonsurgical Retreatment

Nonsurgical retreatment is carried out to regain access to the entire canal system to allow adequate shaping and cleansing to remove any residual microbial flora.

There have been far fewer outcome studies to assess the rates of healing of retreated teeth, and they have the same deficiencies as those on primary root canal treatment. The results of the studies with a higher level of evidence are provided in Fig. 50.5.

It can be seen that the overall healing rates may be some 10% less than for primary treatment. The advent of the clinical microscope and of dedicated ultrasonic instrumentation has allowed clinicians to identify previously untreated canals and to remove obstacles, both natural and iatrogenic, more successfully and predictably. However, this evidence is anecdotal and yet to be reflected in more recent outcome studies on retreatment. It has also been reported by Gorni and Gagliani (2004) that healing rates are highly significantly lower when the original canal anatomy has been altered iatrogenically during the primary treatment instrumentation procedures.



50.4 Nonsurgical retreatment I

Left: Periapical radiolucencies in relation to teeth 32 and 31—old silver pin fillings in situ.

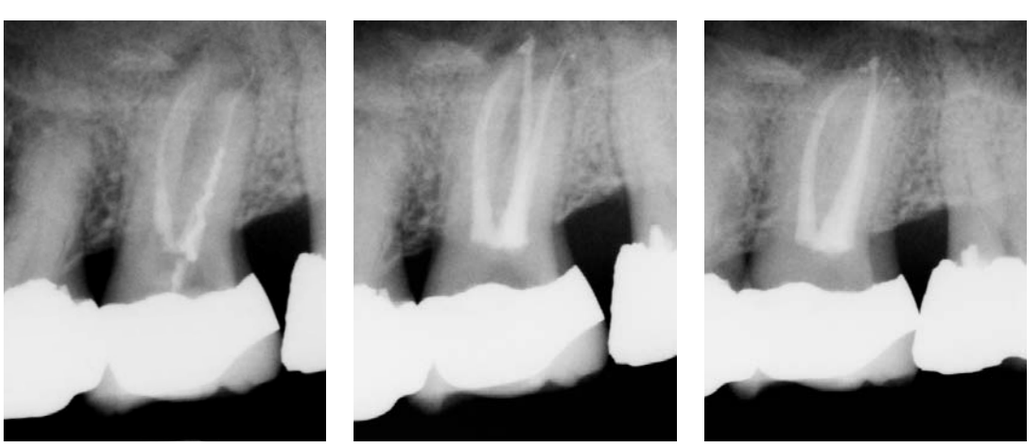
Middle: Successful retreatment of teeth 32, 31, and 41.

Right: Radiograph taken 1 year later. Significant but yet incomplete healing apically around 31; around tooth 32 there is only a slight regeneration. The prognosis remains uncertain.

Author(s)	Number of teeth	Follow-up (years)	Complete healing (%)	Incomplete healing (%)
Selden 1974	52	1.5	88	
Bergenholtz et al. 1979	234*	2	75	12
Molven and Halse 1988	98*	10–17	71	
Allen et al. 1989	596	≥ 0.5	73	12
Sjögren et al. 1990	94*	8–10	62	
Sundqvist et al. 1998	54	4	74	
Kvist and Reit 1999	47	4	58	
Farzaneh et al. 2004	103	4–6	81	

* Number of treated roots, not teeth

50.5 Studies of the success of nonsurgical retreatment



50.6 Nonsurgical retreatment II

Left: Periapical lesions at the apices of the incompletely filled root canals of tooth 26; note also the overfilled material in one canal as well as a fractured Lentulo spiral.

Middle: Appearance following successful nonsurgical retreatment.

Right: Radiograph taken 1 year later. Complete healing of the apical region.

Surgical Retreatment

Should symptomatic lesions still persist following nonsurgical retreatment, or if access to the entire root canal system is blocked by the presence of a post, a surgical approach may be necessary. While most restorations, including posts, may be removed successfully, it might involve the destruction of a large fixed prosthesis, which is unacceptable to the patient. Some posts are overly large and removal might endanger the remaining root structure. In addition, posts luted with resin cements may also prove resistant to removal.

Apical surgery has been performed for many decades, but has not always been associated with high levels of long-term healing. Friedman et al. (1991) and Frank et al. (1992) reported "failure to heal" rates of 35%–42%.

The philosophy of surgical intervention has now evolved significantly since the above reports were published. There is general agreement that if the accessible segment of the root canal system is thoroughly re-treated nonsurgically first, the healing rates following any subsequent surgical procedure are much higher (Grung et al.,1990). Changes in magnification, flap design, root resection, and particularly root-end preparation involving ultrasonic or sonic tips, designed to prepare some 3 mm down the long axis of the canal, have led to marked improvements in healing rates.

There have been a number of studies published, many of which are tabulated below (Fig. 50.7), since the advent of these new techniques, although often incorporating only a short observation period, and subject to the same shortcomings of the studies given above. Friedman (2005), an established authority in this area, has argued for the inclusion of the term "functional," which combines complete and incomplete healing, of those teeth that may still exhibit unaltered areas of radiolucency, but are symptomless and surviving.

Thus far, the trend to improved healing rates is highly encouraging.

Conclusions

It is essential for the clinician to have sound and current knowledge of the likely outcome of endodontic treatment. Patients are entitled to be informed of the expected outcome of any proposed treatment procedure, as well as that of the alternatives. The following means provide approximate, yet easily remembered, optimal healing rates for the different treatment modalities. The figures may change with time, but provide a reasonable mean of all the existing outcome studies:

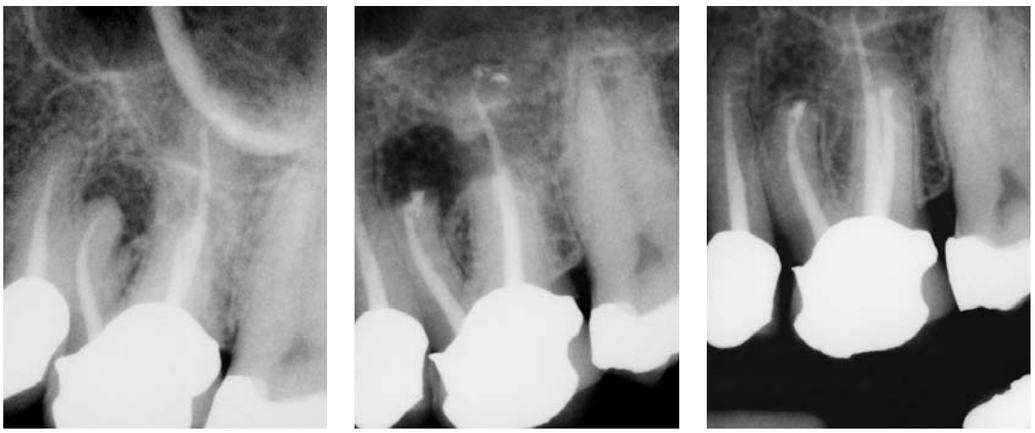
- vital or recently necrotic pulps: 95%
- in the presence of AP: 85%
- nonsurgical retreatment with AP: 75%
- surgical retreatment alone: 65%
- surgical retreatment following nonsurgical retreatment if appropriate and with current treatment modalities: 85%

In the future, one would expect far better prospective controlled outcome studies of primary root canal treatment, nonsurgical, and surgical retreatment, with significant patient numbers and adequate observation periods of 4 or more years. Only then will we have a clearer picture of the optimal rates of healing of apical periodontitis.

New approaches to treatment, as well as the quality of treatment provided, would then be assessed against such benchmarks.

50.7 Studies of the success of surgical retreatment

Author(s)	Number of teeth	Follow-up (years)	Healed (%)	Functional (%)
Friedman et al. 1991	136	0.5–8	44	67
Frank et al. 1992	104	>10	58	
Sumi et al. 1996	157	0.5–3		92
Testori et al. 1999	134	1–6	78	87
Zuolo et al. 2000	102	1–4	91	92
Rahbaran and Kim 2002	129	>4	37	80
Rud et al. 2001	834	0.5–12	92	93
Rubenstein and Kim 2002	59	5–7	92	>92
Chong et al. 2003	108	2	90	96
Wang et al. 2004	94	4–8	74	91
Gagliani et al. 2005	231	5	78	89



50.8 Surgical retreatment I

Left: Completed root canal treatment; the canal orifice of mb2 was not found. Healing of the lesion on the mesiobuccal root had not progressed.

Middle: Appearance following surgical retreatment. Curettage of the lesion, resection of the mesiobuccal root, identification of the mb2 canal, and retrograde closure of both mesiobuccal roots.

Right: Radiograph taken 1 year later. Complete healing in the region of the mesiobuccal root apex.

50.9 Surgical retreatment II

Left: Tooth 46 with an extensive lesion and an incomplete root canal filling. A suspected root fracture could not be verified.

Middle: Appearance following successful nonsurgical retreatment.

Right: Appearance 1 year later. The tooth is functional and symptom-free.

50.10 Surgical retreatment II

Left: Six months later: The patient presented with pain and a buccal swelling. Examination revealed a fracture of the mesial root.

Middle: To retain the tooth, a hemisection was carried out.

Right: After 2 years of normal function, the patient again presented with pain. The osseous resorption mesial to the distal root led to suspicion of an additional fracture or incomplete seal around the area of the short post, where filling material had been unnecessarily and somewhat radically removed.

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Basic Principles

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